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GIS Analysis of Dvāravatī Dharmacakras and the Rise of Buddhism in Thailand

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GIS ANALYSIS OF DVĀRAVATĪ DHARMACAKRAS AND THE RISE OF BUDDHISM IN THAILAND

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ABSTRACT

This dissertation explores how GIS as well as spatial and statistical analyses could be used to advance the understanding of Dvāravatī settlement and Dharmacakras locations. The research employs archaeological and geographical parameters to measure and quantify the patterns of Dvāravatī settlements, Dharmacakra locations, their interrelationship, and their relationship with environmental setting. The different types of spatial analyses, parameter settings within each analysis, and approaches are used to examine and explore the differences and commonalities of these variables at three different geographic levels: national, regional, and river basin levels.

Four distinct approaches are incorporated in this study. Chi-Square analysis shows significant relationships between sites and certain spatial variables, including geology type, soil type, distance to the closest river, and elevation. The patterns of base and felly on Dharmacakras reflect an influence of their geographic locations and neighboring cultures. Currently, neither number of Dharmacakras nor their locations within the same site are adequate to indicate the regional centers or the boundary of Dvāravatī culture. However, the number of Dharmacakras relate to site-size which may highlight an importance of those sites. Additionally, the inscriptions found on Dharmacakras emphasize a significant knowledge of Dvāravatī artisans on the heart of Buddha's teaching, the chain of causation, and the Four Noble Truths. These carefully selected texts are considered appropriate to be displayed on the Dharmacakras since both texts and Dharmacakras represent the first teaching of the Buddha, *Dhammacakkappavattana Sutta*. The KDE illustrates that the density of sites varies among three geographic levels. In general, Central Plain area and the river basins within this area have higher site density than other parts of the country. The greatest density is existed along the major rivers (e.g., Pang Prakong) or circled around the intersection of tributaries of the main rivers (e.g., Upper Chao Phraya). The NNA

reveals a unified clustered pattern of Dvāravatī settlements and Dharmacakra locations at the national level, but the patterns vary from region to region and from river basin to river basin. Rank-size distribution analysis reveals a convex pattern of moated sites and Dharmacakra sites throughout the country which can be attributed to low system integration. Each settlement may be inhabited by an autonomous social group. Additionally, it may indicate the hindrance of communication by topography and poor transportation networks or discontinuous hierarchy.

The results presented in this dissertation provide scholars with the necessary approaches to further investigate the settlement pattern in different cultures and scales based on possible available data.

CHAPTER 1

INTRODUCTION

The purpose of this study is to examine the spatial distribution pattern of Dharmacakras (the Buddhist Wheels of the Law/ the Wheels of Dharma) in relation to the rise of Dvāravatī culture (spanning late 6th– 11th centuries CE) and Buddhism in Thailand. Additionally, to better understand the environmental and social context, the spatial distribution of Dvāravatī settlement, Dharmacakra locations, and environmental setting were investigated at three different geographic levels, by national, regional, and river basin levels. Dvāravatī is one of the oldest religious cultures and artistic proto–historic periods of Thailand and Southeast Asia (Krairiksh 2012; Revire 2013). Different from the Khmer Empire that was established around Angkor, Dvāravatī history cannot be written due to a lack of epigraphic evidence. Its center, geographical extent, and political organization remain unclear (Brown 1996; Murphy 2013b).

The interpretation of spatial distribution of Dharmacakras is useful for understanding the rise of Dvāravatī culture and the spread of Buddhist practice. These sculptures might have served as political and religious symbols which could provide unique means of tracking rulers' power, kingdom's center, or boundary. The locations of Dharmacakras may have the potential to disclose the types of activities, intended audience, or environment. Unfortunately, most of the known Dharmacakras are not systematically excavated, and have limited information about their original locations. Most of Dharmacakras are currently stored in national museums, private collections, and temples, while a few of them remain at the original sites. The study of spatial distribution of Dvāravatī settlement and its environmental setting may be useful to better understand and shed the light on its center, geographical extent, and political organization.

This research employs field survey data of Dharmacakras and archival data of Dvāravatī settlement. The fieldwork was conducted during December 2015–February 2016 in Thailand at sites where Dharmacakras were present, major Dvāravatī sites, and the crafting material sources (see Appendix A for field survey detail). The geographical position and elevation of these sites were systematically recorded by Global Positioning System (GPS). Additionally, photography and a survey of physical environment were performed (Appendix B and C). By overlaying the cutting stone sites with geology layer, reveals potential of stone sources. The research employs the use of GIS as well as statistical and spatial analyses including Nearest Neighbor Analysis (NNA), Kernel Density Estimate (KDE), and rank-size analysis in examining and exploring the Dvāravatī settlement pattern, Dharmacakra locations, their interrelationship, and environmental setting.

1.1 Research Questions

Three key questions are addressed: 1) is there a relationship between Dharmacakras and Dvāravatī settlement? 2) is there a relationship between the spatial location of Dharmacakras and their art styles? 3) what are the functions of Dharmacakras and how can Dharmacakras be linked to the political organization in Dvāravatī culture and the rise of Buddhism in early Thailand? In relation to these questions, three hypotheses are proposed: 1) there is a correlation between number of Dharmacakras and the size of Dvāravatī sites; 2) there is a relationship between spatial location of Dharmacakras and their art styles; and 3) there is a significant function of Dharmacakras which may be served as symbols of religious/administrative centers or indicated the kingdom boundary. Presumably, if the Dharmacakras served as the symbols of sacred or administrative centers. Subsequently, Dvāravatī site which has higher number of Dharmacakras should have higher number of sites surrounded it.

The archaeological and geographical evidence suggests that moated sites, which refers to the site surrounded by moat(s) and embankment(s), were associated with the emergence of Dvāravatī civilization (Bronson and Dales 1973; Eyre 2010; Indrawooth 1999). Among Dvāravatī-style artifacts found within these sites, stone Dharmacakra represents the most comprehensive surviving evidence for early Buddhism in Thailand. Dharmacakras were numerously found in Dvāravatī culture (Brown 1996) whereas only few of them were found in Mekong river delta such as Oc Eo in southern Vietnam and Wat Phu in southern Laos (Indorf 2014). Several Pāli inscriptions are found either on the wheels of Dharmacakra or on their supporting pillars (Krairiksh 2012). These Pāli inscriptions were copied directly from the canonical texts (Saraya 1999). Therefore, Dharmacakras might have been used as religious symbol or as declaration of the holiness associated with supernatural power of rulers. Brown (1996) suggests that Dharmacakra was not only religious symbol but had a political function based on their distribution over a large geographical area at the same time. This spread of the Dharmacakras may have been politically motivated and suggests some new aspects of Indianization process (Brown 1981:287). Brown indicates that the ruler's power would be maintained through military and use of symbolism and religion (Brown 1996).

Currently, no comprehensive database of Dharmacakras exists. The research on the Dvāravatī Dharmacakras' art done by Brown (1981 and 1996) presently represents the most comprehensive work. Forty–two Dharmacakras were reported in his study, but his work does not include a map showing the regional distribution of the Dharmacakras, or a systematical table of these data (Brown 1981; Brown 1996). This study fulfills a function and details needed for information regarding the locational distribution, sizes, motifs, and inscriptions present on Dharmacakras. This study focuses on the spatial distribution of Dharmacakras and their relationship to Dvāravatī settlement. Currently, most of literature discusses only Dharmacakras' artwork, but there is no comprehensive study on spatial distribution. This research searches to answer how much the geographic location shaped the patterns or motifs of the Dharmacakras.

To achieve the research goals, archaeological archives of Dvāravatī Dharmacakras, Dvāravatī settlement, and their environmental setting were investigated. In addition, the study on moated sites during Dvāravatī period were collected from previous research (such as Boyd, et al. 1999; Clarke 2012; Higham, et al. 1982; Moore 1986; Mudar 1993 and 1999; O'Reilly 2014; Supajanya and Vanasin 1980, 1984; Welch 1985; Wilen 1982). Several software programs were incorporated in this analysis, including ArcMap 10.3, Jmp Pro 13, CrimeStat 4.02, Microsoft Excel, and Surfer 10. These tools and softwares were applied with quantitative methods and spatial analysis to map and analyze the spatial distribution patterns of Dharmacakra locations and Dvāravatī settlements. Consequently, the research tests whether Dharmacakras are a feasible case study to explain the spread and development of Buddhism and political organization in Thailand during the Dvāravatī period. Finally, spatial and archaeological databases of Dvāravatī settlement and Dharmacakras were developed. The database can be used as a resource for academics to assist in the preservation and research on these objects. The final product of this research can be used by the local archaeological service as a cultural heritage management tool and may serve as a model in similar cases or apply to further future research.

1.2 Research Objectives

To collect archival and field survey data of Dharmacakras and Dvāravatī sites

To establish a GIS database of Dvāravatī sites and Dharmacakra information

To reconstruct the environmental setting of Dvāravatī sites and Dharmacakra locations

To analyze the spatial pattern of Dharmacakra locations and Dvāravatī settlements

To investigate the relationship between Dharmacakras and Dvāravatī settlements

To investigate the relationship between Dharmacakra art styles and their spatial locations

To analyze rank-size distribution of Dvāravatī sites

1.3 The Conceptual Framework

The goal is to create an understanding on the patterns and location of Dvāravatī settlements as well as the distributions of Dharmacakras by using spatial and statistical analyses to analyze data collected from field survey and secondary sources. The GIS provides crucial spatial analysis tools such as proximity, density, nearest distance, overlay, and intersection analyses. The site distribution patterns play a role in understanding the Dvāravatī settlements. The distribution of these sites is the result of cultural and spatial process. The distribution of points may have various patterns which could be regular, random or clustered. In order to reconstruct the environmental setting of Dvāravatī settlements and Dharmacakra locations, their location characteristics must be analyzed. A combination of GIS and spatial statistics plays a crucial role in interpreting the distribution of Dvāravatī settlements. These settlement patterns are analyzed at three different geographic levels, namely national, regional, and river basin levels to better understand the environmental setting of Dvāravatī settlements.

1.4 Chapter Organization

This section summarizes the chronological order of research from introduction to the conclusion and discussion. The structure of the research is therefore divided into the following chapters.

1.4.1 Chapter 1 Introduction

This chapter provides an introduction and general background information about Dvāravatī period and Dharmacakras. The research questions, hypotheses, and anticipated results are presented. The conceptual framework and chapter outlines are also stated in this chapter.

1.4.2 Chapter 2 Literature Review

This chapter discusses empirical and theoretical information about the geographic backgrounds of Thailand which include geology, hydrology, soil, and geographic region in order to reconstruct the environmental setting of the past. In addition, this chapter also presents the Dvāravatī culture, moated settlements, and Dharmacakras, including their characteristics, types, and motifs. Also in this section, there is a general discussion on the rise of social complexity and civilization in Southeast Asia and Thailand. The chapter reviews some of the concepts such as GIS in archaeology, spatial analyses, settlement pattern analysis, and spatial statistics. The three spatial levels of Dvāravatī settlement analysis (national, regional, and river basin levels) are also presented.

1.4.3 Chapter 3 Materials and Methods

This chapter presents the overview of materials, approaches, and processes used in achieving this research. The field survey conducted during December 2015–February 2016 in Thailand is outlined. Additionally, the data collection methods and sources (primary and secondary) are documented in this section. This chapter includes data collection approaches and sources; types of data and their characteristics in relation to study areas; types of software used; functions and methods used to analyze data.

1.4.4 Chapter 4 Results and Discussion

This chapter presents the results and discussion obtained in analyses of the distribution of Dvāravatī sites and Dharmacakras, as well as their environmental characteristics and relationships. The similarities and differences among three different levels of analyses are also given in form of maps, statistical tables, graphs, and charts. The chapter focuses on the reflection on results obtained in the study with an aim of establishing the database of Dvāravatī settlement and Dharmacakra information. The apparent occurrences of settlement patterns in some areas such as distance to the closest river are also reviewed and discussed.

1.4.5 Chapter 5 Summary and Conclusions

This chapter presents a general summary and conclusions. It highlights a summary of the methods and results as well as recommendations on appropriate further research. It also notes some limitations of the research along with possible recommendation for further research. Lastly, the potential further research areas of Dvāravatī settlements and Dharmacakras have been suggested.

CHAPTER 2

LITERATURE REVIEW

To understand the roles of internal and external factors in the development of settlement patterning during Dvāravatī period, it is necessary to examine the geographic setting. In this chapter, the Dvāravatī culture and Dharmacakra are discussed. Afterward, the environmental setting in each region of Thailand in which the populations developed settlements is examined. In addition, settlement pattern analysis, the use of GIS in archaeology, spatial analysis, and spatial statistics are presented.

2.1 Dvāravatī

For several decades, Dvāravatī culture has been studied by both Thai and international scholars, but the dating, geographical extent, historical, and political organization remain unclear. The name Dvāravatī was adopted from the references made by Chinese monks' pilgrimage in the 7th century CE, the inscription in Sanskrit found on coins, and as part of official titles of later capitals of Thailand, including Ayutthaya (founded in 1350 CE) and Ratanakosin or Bangkok (founded in 1782 CE) (Rohanadeera 1988).

The Dvāravatī culture has been roughly dated, primarily by art historical association with post-Gupta India, to ca. 600-1,000 CE (Barram and Glover 2008). Dvāravatī as a political unit appears to have existed approximately between the 6th to 9th century CE, while the art style and culture extended to the 11th century (Murphy 2010; Revire 2013). However, recent field excavations at early-Indian influenced sites in Cambodia, Vietnam, and Indonesia indicate that Indian cultural influences in Southeast Asia were well established before the 5th century CE (Barram and Glover 2008). The recent radiocarbon dates from Tha Muang mound at U Thong and Chansen indicate that Indian cultural influences which are commonly related to Dvāravatī culture were already existing in Western Thailand before the 5th century CE (Barram and Glover 2008). Dvāravatī art style covered a larger geographical area than that of the political unit. Archaeological evidences indicated that Dvāravatī time was a predominantly Buddhist society. Mostly, information about Dvāravatī period is derived from the archaeological evidences which have been discovered at the major sites. These evidences include several brick stūpas, sculptures, Buddha images, stucco, and Dharmacakras (Figure 2.1).

Figure 2.1: a) Stele with Buddha sheltered by Naga's hood, from Wat Pradu Songtham, Phra Nakhon Si Ayutthaya, b) Dharmacakra found at Wat Saneha, Nakhon Pathom, c) Relief depicting female musicians found at Ku Bua, Ratchaburi (Photos by Areerut Patnukao, from Bangkok National Museum)

Most of Dvāravatī sites were surrounded by earthen–wall moat. These sites are found mainly in the Central Plain, including Nakhon Pathom, Lop Buri, and Suphan Buri. A small number of sites are found to the west, east, north, northeast, and south of Thailand (Figure 2.2) (Khunsong, et al. 2011; Revire 2013; Vacharasin 2012).

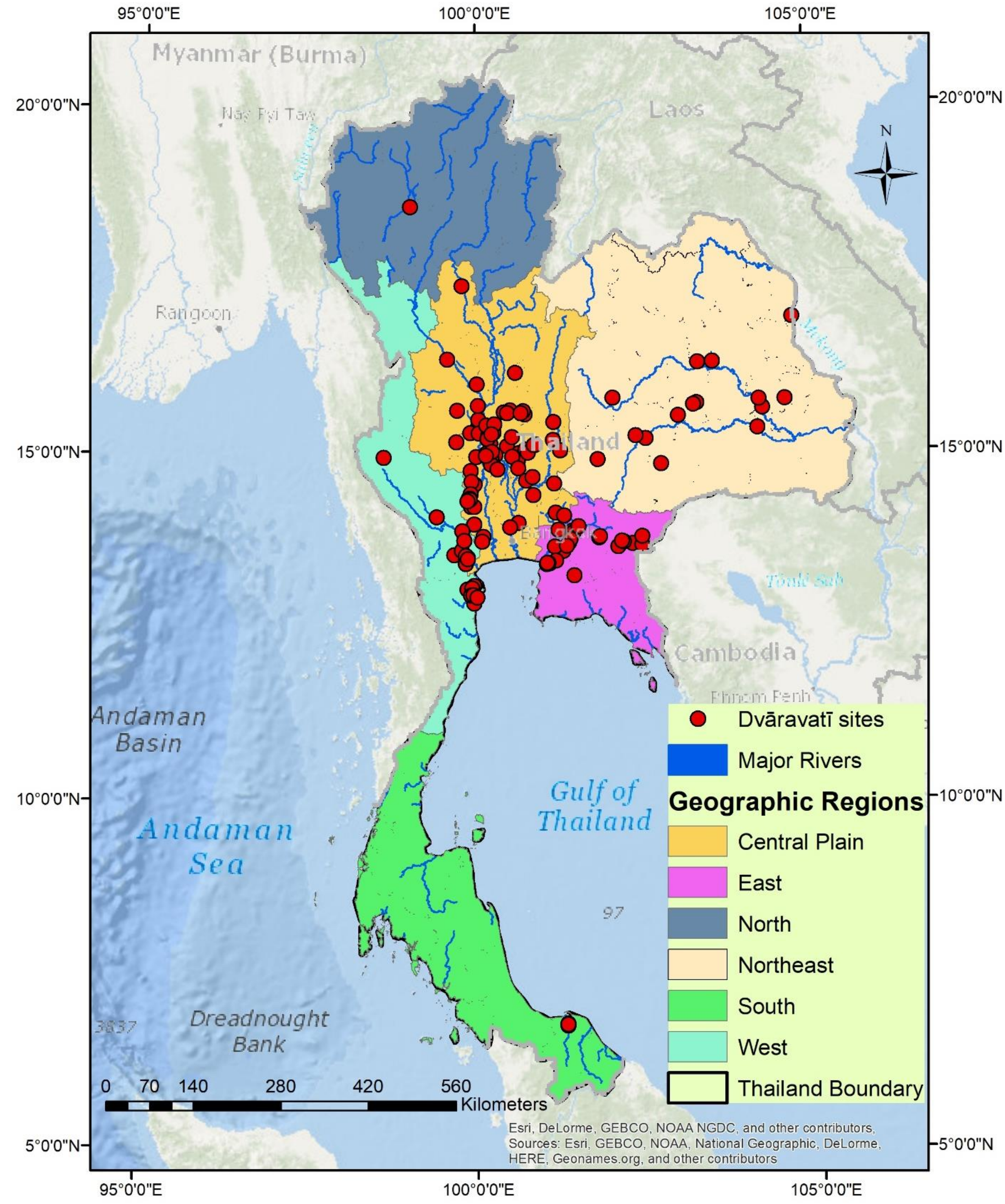


Figure 2.2: The distribution of Dvāravatī sties, map by Areerut Patnukao, basemap: USGS, Esri, NOAA, and other contributors

2.1.1 Culture

The Dvāravatī, the earliest Buddhist kingdom in central Thailand, existed between the late 6th to 11th centuries CE (Higham and Thosarat 2012; Indrawooth 2008a; Lyons 1979). However, the exact time span is still debated. Dvāravatī civilization had retained a distinguish cultural identity until the 10th century, then it was gradually assimilated into the Khmer empire (Briggs 1999; Mudar 1999). A number of scholars have identified Dvāravatī culture based on Chinese references (Brown 1996). In 1928, Coedès identified the Buddhist kingdom referred to by Chinese monks as Xuanzang (Hsuan–Tsang) and Yijing (I–Tsing or I–Ching) of the 7th century CE under the name of To–lo–po–ti. This kingdom was situated to the west of Isanapura (Cambodia) and to the east of Sri Ksetra (Myanmar) (Wales 1966). In 1963, two silver medals dating to the 7th century CE were found at Nakhon Pathom. Each was inscribed in Sanskrit phrase "Sridvaravatisvarapunya," which means "meritorious deeds of the King of Dvāravatī" (Figure 2.3) (Higham and Thosarat 2012; Indrawooth 2008a; Revire 2013; Wales 1966). This inscription confirmed the existence of a Dvāravatī kingdom (Higham and Thosarat 2012; Indrawooth 2008a; Revire 2013; Wales 1966). In addition, Dvāravatī means "which has gates" (Higham and Thosarat 2012:225). Later, a number of silver coins were discovered from other Dvāravatī sites such as U Thong and Ban Ku Muang (Centre 2006; Higham and Thosarat 2012). In addition, the knowledge of this early civilization draws on excavations at a series of large moated sites along the margins of the Central Plain. Most Dvāravatī sites were located at the stream or river which supplied water to an encircling moat (Higham and Thosarat 2012).

Figure 2.3: Inscribed silver medal from Wat Phra Pathom Chedi, Nakhon Pathom province. The text is in Pallava script, Sridvaravatisvarapunya, which means meritorious deeds of the King of Dvāravatī

Southeast Asia is geographically on the trade route between India and China. Southeast Asians exchanged goods with India during the time of Maurya to Sunga dynasties (200–1 BCE) (Museum 2009). At that time, India was connected to the west much like Greece, Rome, and Persia (Museum 2009). Trading between India and Southeast Asia flourished during the time of the Kushana and Gupta dynasties (or Indo–Roman Period), the 1st–4th centuries CE (Museum 2009). During this period India and Rome were significant trade partners. Rome established several trading stations at the major ports on both east and west shores of India (Museum 2009). From the 5th–6th centuries CE, Southeast Asia accepted and adopted Indian civilization through religions, cultures, traditions, trading, and languages (Museum 2009). The Bronze Roman Lamp found at Pong Tuk, Thamaka district, Kanchanaburi province, presently kept at National Museum Bangkok, was evidence of this expanded trading network associated with the Dvāravatī period (Clarke 2012) (Figure 2.4). In addition, Dvāravatī arts were consequently influenced by Indian culture. For example, the symbolism on Dvāravatī coins was derived from Indian precedents of the 1st to 4th centuries C.E, including the cow with calf, the conch, and the rising sun (Higham and Thosarat 2012). The coinage confirms the importance of royalty (Indrawooth 2008a).

Figure 2.4: The Bronze Roman Lamp found at Pong Tuk, Thamaka district, Kanchanaburi province, presently kept at National Museum Bangkok (Museum 2009:20)

Dvāravatī culture adapted numerous elements of Indian culture, such as the system of coinage, sealing, languages (Pāli and Sanskrit), religious beliefs, arts, town plans, architecture, ceramics, the concepts of state kingship, as well as instruments and dancing poses (Indrawooth 2008a). Nevertheless, Dvāravatī culture represents a distinctive development characterized by predominant Buddhism. Dvāravatī culture shows a significant degree of homogeneity in terms of art, material culture, and religion, but the political boundary, kingship, economics, and regional and ethnical aspects have not been sufficiently defined.

However, the study of Dvāravatī period is lacking substantial dating record. Most of the published radiocarbon dates associated with Dvāravatī cultural items tend to date to an earlier period (Barram 2003; Glover 2011). The results of dated samples from well–excavated contexts at U Thong conducted by Watson and Loofs (1970) strongly indicated that many elements such as the ceramics associated with Dvāravatī culture should be pushed back at least 200 years before the generally accepted which beginning date of around 600 CE (Glover 2011; Loofs and Watson 1970).

2.1.2 Settlement

For several decades, numerous scholars have integrated archaeological information about settlement patterns, agricultural practices, and excavations to study complex polities of Southeast Asia (Boyd, et al. 1999a; Hagesteijn 1989; Hall 1985; Moore 1988a; Mudar 1999; O'Reilly 2014; Welch 1985). The interest in the human settlement in Thailand has been continuedly studied for over century. In 1906, Prince Damrong Rajanubhab visited and illustrated a large, uninhabited mound in the upper Mun Valley of northeastern Thailand, called Non Muang Kao (Mound of the Ancient City) (Figure 2.5) (Higham 2011). This site is one of hundreds of moated prehistoric settlements concentrate in the Mun river valley and extending northward into the Chi valley and southward into the Dang Raek range in northern Cambodia (Higham 2011).

The moated site is normally defined by a site surrounded by moat(s) and embankment(s). It can be different in shape, size, and number of moats and embankments surrounding it. For instance, in Northeastern Thailand, moated sites normally have a mound up to 5 m in height with between one and five surrounding moats and embankments. Some of the moats surrounding these sites are large with over 100 m in width (O'Reilly and Scott 2015).

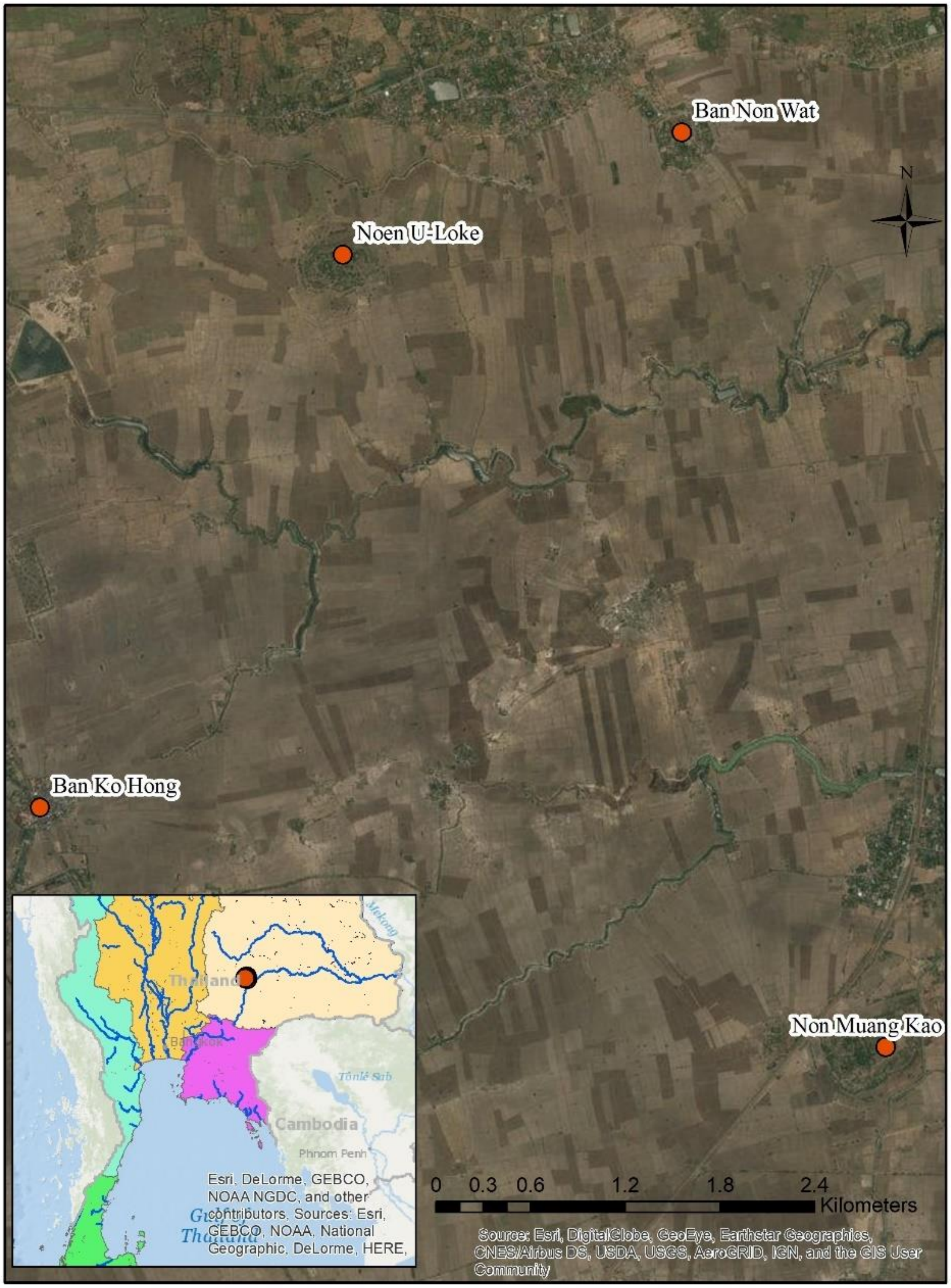


Figure 2.5: The distribution of sample moated sites in Mun Valley in Northeast of Thailand during Iron Age, (after Higham 2011: Figure 3), map by Areerut Patnukao, basemap from Esri, USGS, and other contributors

During the WWII, Williams-Hunt pointed out several moated sites (mounds encircled by channels) which appeared in aerial photographs in the Mun and Chi rivers in northeast Thailand, but he did not specify the ages of these sites (Williams-Hunt 1950). Later, many scholars studied these moated sites, especially in the Northeast (Boyd, et al. 1999b; Higham 2011; Higham, et al. 1982; Moore 1986; Moore 1988a; O'Reilly and Scott 2015; O'Reilly 2014; Welch 1985; Welch and McNeill 1991; Wilen 1982) and Central Plain of Thailand (Eyre 2006; Mudar 1993; Supajanya and Vanasin 1984; Vallibhotama 1984).

Ancient moated sites in Northeast Thailand were identified in the early 20th century and have been studied ever since. These moated sites emerged during the Iron Age (c. 500 BCE–CE 500) but the purpose of the moats remains unclear. Pedestrian survey and aerial photographs have aided to understand the distribution of these sites across the landscape and has shown that they concentrate in the Mun and Chi Valleys of the Khorat Plateau (O'Reilly and Scott 2015). The Mun Valley holds several a number of large, moated prehistoric sites, for instance Ban Non Wat, Noen U-Loke, Non Muang Kao, and Ban Ko Hong (Figure 2.16). Noen U-Loke consists of at least five moats and ramparts. The site has a maximum diameter of 0.410 km. Ban Ko Hong has diameter of 0.44 km. Non Muang Kao is one of the largest moated sites with a maximum diameter of 0.65 km, while Ban Non Wat is circled by at least two moats and banks and has a diameter of 0.33 km and only 2 km away from Noen U-Loke (Higham 2011). Recently, by integrating the cultural sequences from three excavated sites in the Mun Valley, namely Ban Non Wat, Noen U-Loke, and Non Muang Kao, it is possible for first time in Southeast Asia to trace the complete sequence of the Iron Age (Higham 2011). The radiocarbon datings from Ban Non Wat reveal evidences of the early Iron Age in the context of the preceding six phases of the Bronze Age (see detail in Higham 2011). Most of moated sites in Northeast of Thailand dated back to the Iron Age, although many of them were occupied prior to the Iron Age, and some as early as the Neolithic (Higham and Thosarat 2012). The hierarchical patterns of settlement reflected an early state formation in the period 1,000 BCE–1,000 CE and corresponded with developments in the complexity of social organization (Boyd, et al. 1999a; Boyd, et al. 1999b; Eyre 2010; Higham 2004; O'Reilly 2000; Onsuwan 2002; White 1995). These moated sites were identified by iron working, an increasing population, ploughing agriculture, as well as interregional and international exchange networks (Higham, et al. 1982).

Additionally, several scholars have studied moated sites on the social and cultural origins of these features. These sites are largely investigated on social and sociopolitical aspects in terms of apparent and functional relationships between morphology and utility (Boyd and McGrath 2001). For instance, Moore (1988) studied the relationships between site and landscape in order to find correlation of site location, moat morphology, and soil type distribution (Moore 1988a). Boyd et al. (1999) studied the surface geology of Mun River Valley. They suggested that these moats might represent the adaptation of natural waterways which indicated the importance of the Iron Age human–environment relationships (Boyd, et al. 1999a; Boyd, et al. 1999b). Recently, O'Reilly and Scott (2015) presented the results of a recent archeological survey of the Khorat Plateau in Northeast Thailand using Google Earth satellite imagery. They identified the presence of clusters of moated settlements in these regions through statistical analysis. Their research has built on previous work that cumulatively identified 151 definitive sites. The Google Earth survey has increased this figure by 146 newly resulting in a total of 297 circular, moated sites in the region (O'Reilly and Scott 2015).

Around the 6th century CE, evidence such as moated site of Chansen indicated the emergence of Dvāravatī civilization in central Thailand (Bronson and Dales 1973; Eyre 2010;

Indrawooth 1999). Chansen is fairly small compared to other Dvāravatī moated sites (such as U Thong, Nakhon Pathom, and Ku Bua), but it is situated among Metal Age sites and has been systematically excavated (Eyre 2010). Chansen's moat has a 2 m wide embankment with an oblong shape and encloses an area of about 700 by 700 m (Figure 2.6) (Bronson and Dales 1973). Along the margins of the Central Plain of Thailand, several large moated towns were present during the Dvāravatī period. Vanasin and Supajanya (1980) published the study of moated settlements in the Dvāravatī period by using aerial photographs to identify the moated settlements on the Central Plain of Thailand. They suggested that moated settlements were found mostly at Dvāravatī sites, which were located near rivers. Therefore, streams or rivers supplied water to the moats (Indrawooth 2002; Vanasin and Supajanya 1980). Large religious buildings were constructed within the moats, while small ones were outside (Indrawooth 2002). Major moated sites have been found in the Mae Klong–Tha Chin Valleys such as Nakhon Pathom, U thong, and Ku Bua; in the Lop Buri–Pasak Valley such as Chansen, Sab Champa, and Si Thep; in the Bang Prakong Valley such as Muang Si Mahosot, Muang Phra Rot, U Tapao, and Thap Chumphon; and in the Northeast, such as Na Dune and Muang Sema in Mun Valley, as well as Chaiyaphum and Muang Fa Daed Song Yang in Chi Valley. These moated sites have total enclosed areas range from 0.04 to +6 km^2 (Figure 2.7) (Gallon 2013; Indrawooth 1999; Indrawooth 2002; Mudar 1993; Mudar 1999; Supajanya and Vanasin 1984).

Figure 2.6: Comparison of Chansen (approx. area 0.49 km^2) (upper left) and other major moated sites, U thong (approx. area 0.963 km2) (upper right), Nakhon Pathom (approx. area 6.594 km^2) (lower left), and Ku Bua (approx. area 1.71 km^2) (lower right), map by Areerut Patnukao, basemap from Esri, NOAA, and other contributors

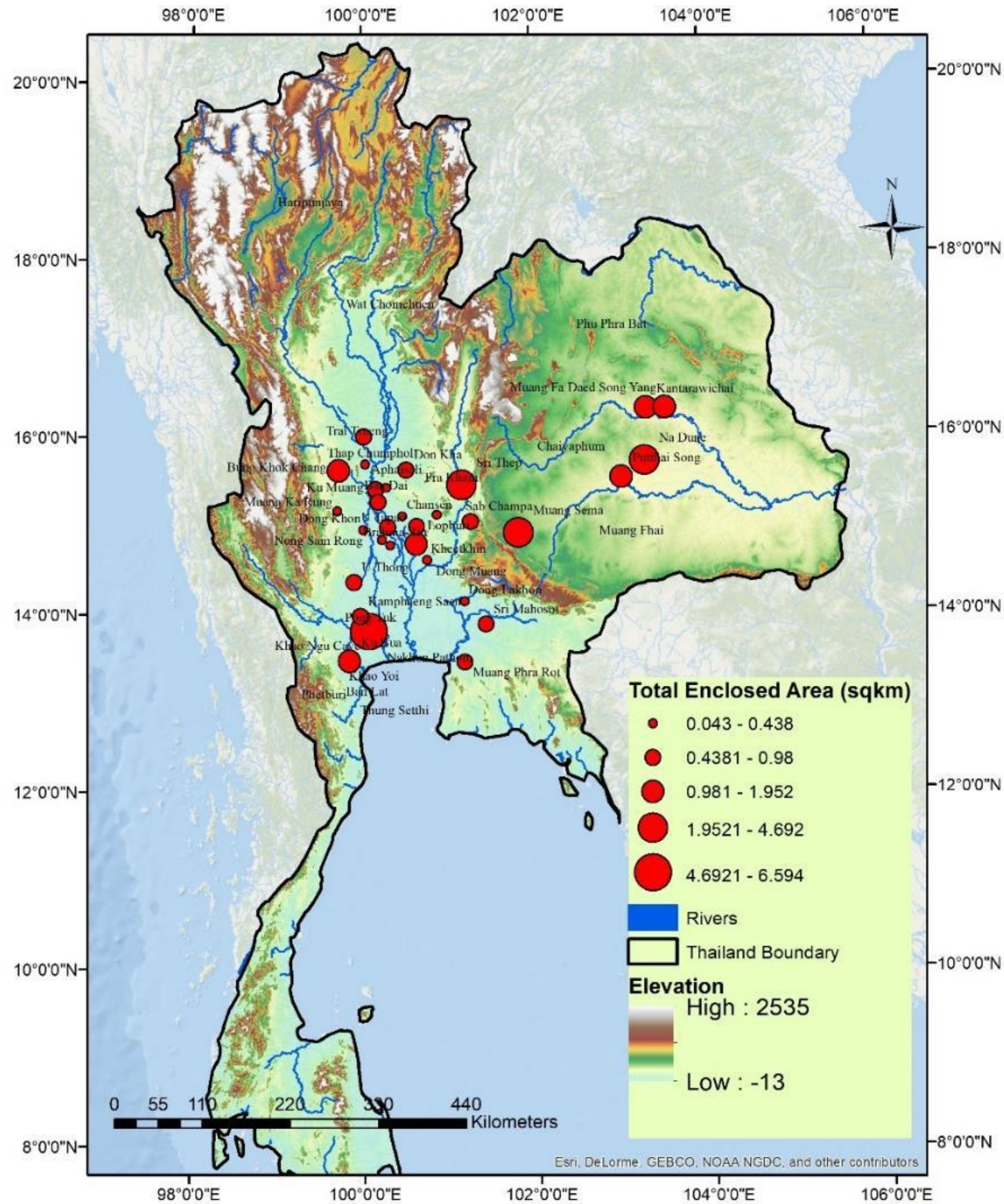


Figure 2.7: Major Dvāravatī moated sites located along major rivers, sites data from Indrawooth 1999: Map 7; Gallon 2013: Table B.1; Mudar 1993: Table 8.2; Mudar 1999: Appendix I (after Supajanya and Vanasin 1980), map by Areerut Patnukao, basemap from Esri, NOAA, and other contributors

2.1.2.1 Origins of Moated Site in Thailand

Presently, the one of the earliest moated sites in Thailand is possibly Khao Sam Kaeo near the east coast of peninsular Thailand. Khao Sam Kaeo was occupied between the early 4th and 2nd centuries BCE (Glover and Bellina 2011). It contains the oldest foreign ceramics found in Southeast Asia such as Chinese earthenware from the 1st and 2nd centuries BCE, as well as several varieties of Indian pottery, including Northern Black Polished Ware and rouletted ware (possibly from south India) (Miksic 2017; Pryce, et al. 2006). These ceramics provide evidence for the early expansion of trade between Southeast Asia and India. The data from Khao Sam Kaeo present the beginning of a sociopolitical system centered on a trade network in maritime Southeast Asia and on the development of agricultural and industrial activities.

Khao Sam Kaeo's general shape and fortification system is more similar to the early Indian cities that emerge in the mid-first millennium BCE than to any contemporary Southeast Asian moated site (Bellina 2016). In northern India, large urban sites varied in form and the proportion of walled sites is greater than in the south of India. These Indian sites include Saheth-Maheth, Balirajgarh, Sisupalgarh, and Mahasthangarh (Smith 2003). Most cities in the north of India were not uniform in plan and appeared to have adapted to local topography, especially with the river. For instance, at Sisupalgarh and Mahasthangarh, the tributaries were canalized to form a moat around the urban zone (Smith 2003:275). These cities were enclosed with earthen ramparts which followed the shape of the natural topography (Smith 2003). The moats may be used for multiple purposes, including warfare, controlling water, restricting the access of outsiders to markets, materializing the civic identity, and generating cohesion (Bellina 2016). Additionally, these moated sites expressed a level of political control which could mobilize and organize the labor to produce and maintain the cities. These major ancient Indian sites range from 0.16 km^2 to above

2.41 km^2 (Allchin and Erdosy 1995). For instance, Pataliputra, the capital of the Maurya empire, has an enclosed area of 3.4 km^2 (Allchin and Erdosy 1995: 207).

Dutt (1925:75-84) stated nine different types of forts in India based on their defensive characteristics; mountain, water, desert, forest, earth, man, mixed, God's, and artificial forts. Mountain, water, desert, and forest forts are the result of natural factors. The earth fort has man-made ramparts made of mud, stone, or brick. The man fort is protected by various allies to defend each other in case of emergency. The mixed fort is combination of mountain and forest forts. The God's fort included inaccessible places such as Mount Everest. The last type is an artificial fort which include all forts that are not protected by nature (Dutt 1925).

In the Ganga Plains of northern India, most of major Iron Age (ca.700-350 BCE) sites were located on the river banks where people utilized clay embankments to prevent flood. During the Iron Age, earthen banks and moats as flood protection are found at sites such as Kausambi, Varanasi, and Pataliputra. During the early historic period (ca.350-50 BCE), these were developed into substantial defensive ramparts. Pataliputra and Kausambi are examples where the clay embankments of the early phase, with certain modifications, were converted to defensive purposes (Indrawooth 2002; Roy 1983). An improvement from the irregular, circular or oval nuclei found in earlier Iron Age sites were found in some Dvāravatī sites. For instance, at Muang Bon in Nakhon Sawan province, an original circular site was extended to encompass a wider area of land where new ramparts and moats were built. At Si Thep and Muang Fa Daed, the grafting on the secondary enclosure are presented. At U Thong, a stone wall for defensive purpose was built on top of clay rampart (Indrawooth 2002).

In the deficiency of radiocarbon dates, Dvāravatī sites are recognized by the existence of distinctive high–fired earthenware pottery (Indrawooth 1985; Mudar 1999), the remains of brick stūpas, and other religious buildings (Glover 2011). Some Dvāravatī sites may have extensive surrounding walls and moats covering many kilometers, but settlement patterns have rarely been investigated (Glover 2011). Languages and arts of Dvāravatī specify the extensive contact with India, but the role and the development of moated settlements to the emergence of social complexity remains unclear (Mudar 1999). Therefore, the study of settlement patterns associated with the distribution of Dharmacakras may broaden the understanding of political organization and geographical landscape of Dvāravatī period.

2.1.2.2 Type of Sites in Thailand

Archaeological sites can often be identified on aerial photographs and geographic maps by their anomalous appearance in natural landscape. Moated settlements are found in most regions of mainland Southeast Asia, but are especially common in Northern, Central, and Northeast Thailand (Moore 1988a). In northeast Thailand, there are three common types of settlements, namely unmoated mounds, moated mounds, and rectangular water storage (baray) sites (Moore 1988a). Previous studies of moated sites in Northeast Thailand have classified the moated sites by terrace, height of earthworks, sizes and shapes of moats, and site profile. Moore (1986) studied the settlement pattern of moated sites in the Mun river basin in Northeast Thailand based on WWII Williams-Hunt Collection of aerial photographs (Moore 1986). Her study suggested that local topography and hydrology were the primary factors influencing the location, shape, and distribution of moated sites (Moore 1988a).

Based on Moore (1988), moated settlements in Northeast Thailand can be divided into two types, water-harvesting and territorial sites. The two types can also be described using the terms "topographic control" and "non-topographic control" respectively (Vanasin and Supajanya 1980). The plan of the moats and earthworks of the water-harvesting sites is controlled by the local terrain, but that of the territorial sites is not. A majority of the water-harvesting sites examined were located on low terrace land at 130-180 m high, and most were close to a waterway. Most water-harvesting sites have a moat-mound-moat profile with the shape of the moats and earthworks repeating the shape of the central mound. The mounds were used for habitation. The mounds rise 1-5 m above the surrounding, generally flat landscape; they are visible on the ground and from the air. The mounds have been built up over centuries. As the water-harvesting sites developed, the mounds were enclosed by additional rings of water and land. A mound can be surrounded by up to four moats. Water has shaped the landscape of the water-harvesting sites, and it is the primary factor to be considered in relation to their survival. The simplest water-harvesting sites are generally found on floodplain areas. The floodplain and terrace combination is the typical location of the water-harvesting moated settlements (Moore 1988b). The water-harvesting sites may have been used for several purposes, for instance, water storage, cultivation of plant and animal protein, and potential local salt manufacture. The adding of another earthwork may increase the defensive abilities and created new and accessible habitats for small game. Many of the water-harvesting moats are now silted up and used for wet rice agriculture, but large portions remain water-filled. Some sites lack an accessible water source; it is possible that once a stream may have filled the moats but has now changed course. Moats could also feed from underground springs, seepage, or rainwater. The trees growing around earthworks would also reduce the evaporation rate of the moats (Moore 1988b).

On the other hand, a territorial site form is not governed by the topography. The territorial site is likely larger and has fewer moats (often only one), but the moats are wider than those found enclosing the water-harvesting sites. In the territorial sites, the moats often have been expanded in one direction only. Some of the territorial sites began as and continued to be territorial sites and always non-topographically controlled. However, some water-harvesting sites became territorial settlements. In terrestrial site, additional moats no longer followed the contours of the mound, but delineated a new continuous zone of land potentially suitable for settlement or agriculture. The change from the water-harvesting to territorial site may date to the second half of the 1st millennium CE. The change in form may indicate a change in function. The terrestrial intensively presented in Central Plain during Dvāravatī period which could signify the change in economic and cultural trade (Moore 1988b). In Central Plain, the plan of moated settlements such as U Thong, Ku Bua, and Nakhon Pathom are closely similar to that of the Northeast territorial sites. Both the Northeast territorial sites and moated settlements in the Central Plain are normally surrounded by a single non-topographically controlled moat (Moore 1986).

Muang Fang is an example of a water-harvesting site, while Muang Sema represents a territorial site (Figure 2.8) (Moore 1988b). Muang Fang has at least 4 moats. The area of the mound and the innermost earthwork/moat pair is about 0.237 km^2. When the second earthwork/moat set is added, the total area increases one-third to about 0.325 km^2. In contrast, the original mound and moat on the southern part of Muang Sema is about 0.375 km^2, considerably larger than the initial settlement at Muang Fang. The second moat added to the norther part of Muang Sema encloses about 1.125 km^2, increasing the site area by four times, to about 1.50 km^2. Muang Sema is located on the western rim of the Khorat Plateau, in an advantageous location for trade with the Central Plain. Several artefacts found in this site belong to Dvāravatī style, including Dharmacakra and a large reclining Buddha (Moore 1988b).

Figure 2.8: Muang Fang is an example of a water-harvesting site (Upper), Muang Sema represents a territorial site (Lower) (satellite images from Google Earth 2017)

Vanasin and Supajanya (1980) classified ancient sites visible on aerial photography throughout Thailand into two major types: shapes that do not depend on physiographic factors (non–physiographic controlled, non–topographically controlled, or territorial site) and those that depend on physiographic factors (topographically controlled or water-harvesting site). In addition, they placed 63 moated sites distributed in the Lower Chao Phraya into eight categories based on their shapes. These moated sites were all considered non–physiographic or non-topographically controlled sites (Vanasin and Supajanya 1980). The eight categories are 1) free-form (e.g., Ku Muang (ES2) in Chachoengsao province), 2) circular (e.g., Muang Bon (CS57) in Nakhon Sawan), 3) oval (e.g., Bung Khok Chang (CS133) in Uthai Thani province), 4) curved corner (e.g., Ku Bua (WS50) in Ratchburi province), 5) angular corner (e.g., Wat Pratu San in Suphan Buri province), 6) polygonal (e.g., U Tapao (CS3) in Chai Nat province), 7) half-nature: half of moat is natural river while another half is man-made (e.g., Sankhaburi (CS2) in Chai Nat province), and 8) multiple: site has multiple moats in different shapes and sizes (e.g., Promtin Tai (CS86) in Lop Buri province) (Figure 2.9 and 2.10). However, based on personal communication with Supajanya in 1985, Moore (1986: 81) stated in the doctoral dissertation that Supajanya groups these moated sites into five major categories: free-form, circular, oval, rounded/curved corner, and angular corner (Figure 2.11A) (Moore 1986; Supajanya 1986). The polygon type may be classified into angular corner. The half-nature and multiple types may be classified into one of these five types.

Nakhon Pathom in Central Plain is a free-form moated site with a canal running from north to south. Both moat and canals were certainly used for transportation as well as territorial separation. The evidences from excavations have revealed the foundations of buildings which appear to have been rebuilt several times between the 7th and 11th centuries CE, signifying contemporaneous occupation with sites such as Muang Sema in northeast (Moore 1988b).

Figure 2.9: 1) free-from (e.g. Ku Muang in Chachoengsao province), 2) circular (e.g. Muang Bon in Nakhon Sawan, the initial phrase was a circle but the expanded oval layers was added later), 3) oval (e.g. Bung Khok Chang in Uthai Thani province, this site also be considered as multiple), 4) curved corner (e.g. Ku Bua in Ratchaburi province) (satellite images from Google Earth, insert plan pictures from Vanasin and Supajanya 1980: Appendix 1)

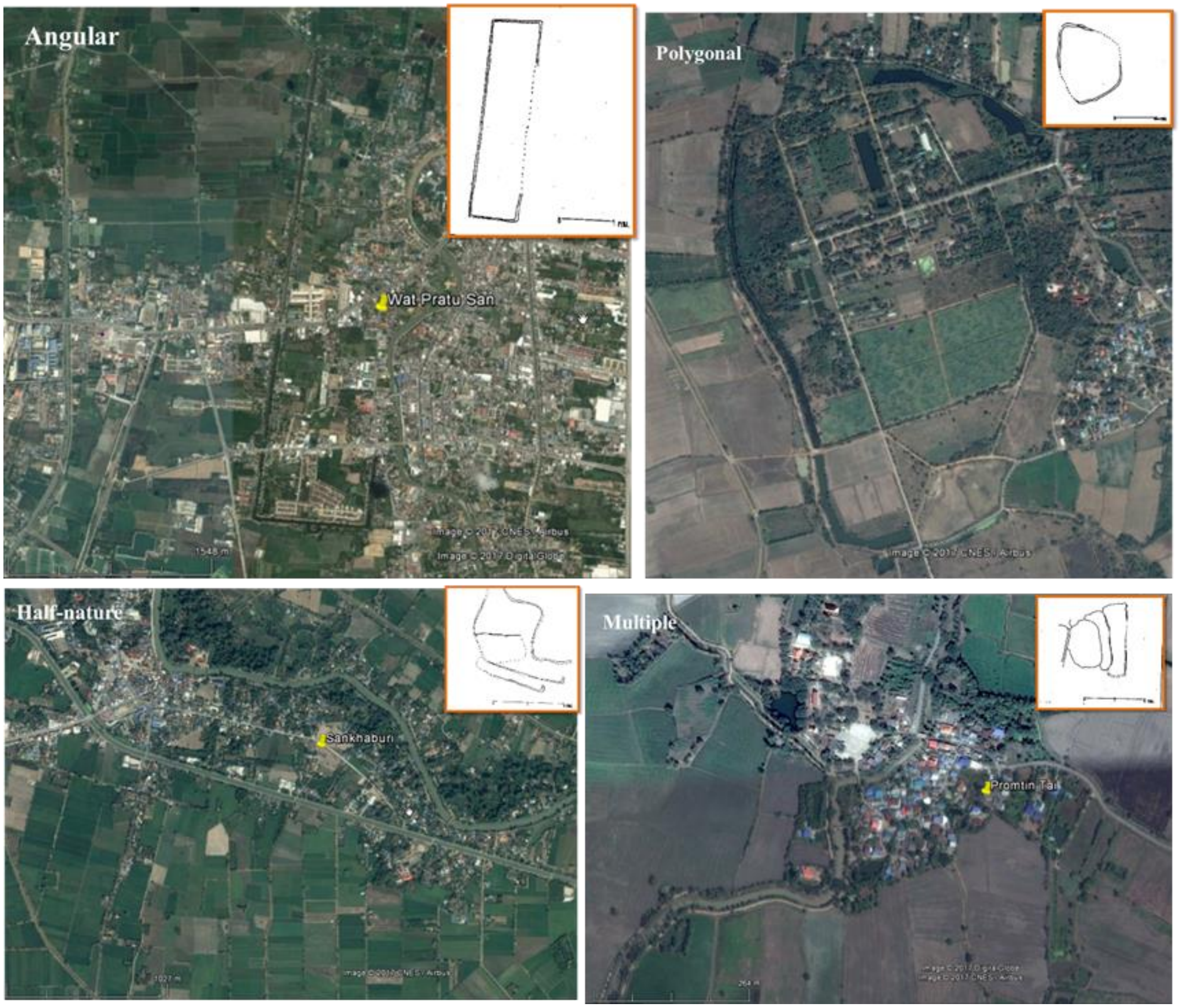
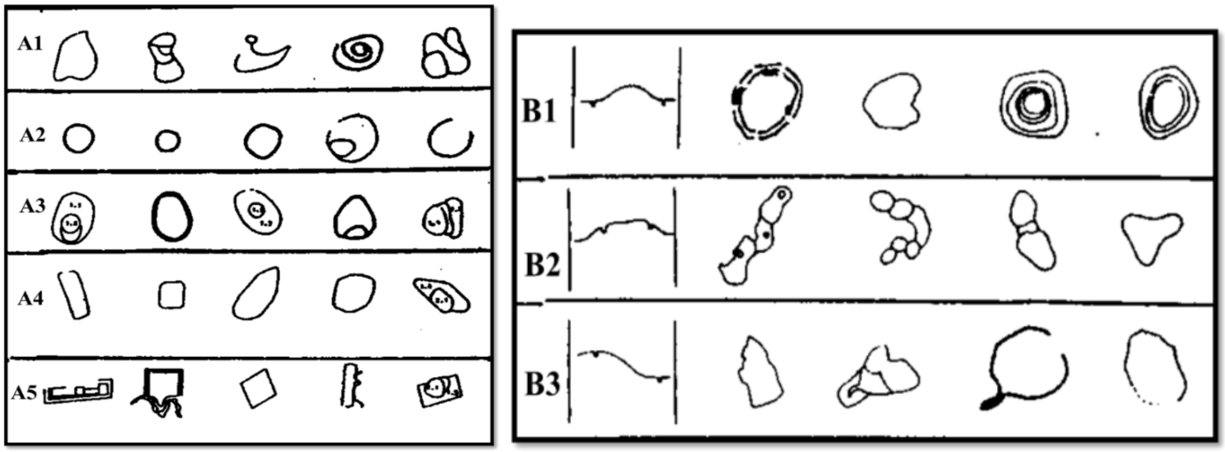


Figure 2.10: 5) angular (e.g. Wat Pratu San in Suphan Buri province), 6) polygonal (e.g. U Tapao in Chai Nat province), 7) half-nature (e.g. Sankhaburi in Chai Nat province), and 8) multiple (e.g. Promtin Tai in Lop Buri province) (satellite images from Google Earth, insert plan pictures from Vanasin and Supajanya 1980: Appendix 1)

In the north and northeast of Thailand, distinct moat patterns were identified. For instance, the moat–mound–moat profile (water-harvesting moated site or topographically controlled site) is commonly found in the Northeastern region. The moat surrounds the foot of a hill (Figure 2.11B1). On the other hand, in the Northern region, it is common to find a moat surrounding the edge of a hill or surrounding the edge and the foot of the hill (Figure 2.11B2 and B3) (Moore 1988b; Supajanya 1986).



A) Non Topographic Control **B) Topographic Control**

Figure 2.11: Classification of moat pattern in Thailand shown in aerial photography; A) Non Topographic Control, shape does not depend on the physiography factors: A1) Free-From shape: dykes and ditches which curve freely, A2) Circular shape: dykes and ditches with smooth curvy lines forming circles, A3) Oval shape: dykes and ditches with smooth curvy lines forming oval shapes, A4) Curved corner shape: dykes and ditches which form straight or near-straight lines with curved corners, A5) Angular shape: dykes and ditches with straight lines forming angular shapes; B) Topographic Control, shape depends on physiographic factors: B1) Surrounding foot-hill: dykes and ditches around the base of a mound or hill, B2) Surrounding edge of hill: dykes and ditches around the crest of a mound or hill, B3) Surrounding edge and foot-hill: dykes and ditches around both the crest and the base of the mound, (after Supajanya 1986: Figure 4, Moore 1988: Figure 5.1)

Vallibhotama (1984) divided moated sites throughout Thailand into floodplain and low terrace sites (Vallibhotama 1984). The term moats and fortification were then used to identify subgroups. On the floodplain, the four types of moated sites identified by Vallibhotama (1984) were:

1) Unmoated mounds elevated over 5 m from the surrounding lowland

2) Single moated sites with the moat greater than 25 m in width encircling a habitation area containing 1–2 large mounds

3) Triple moated sites

4) Fortified settlements with moats and earthwalls, which were indicated as political centers or chiefdom owing to their defensive function implied by the wall.

Low terrace sites were all characterized as being large and fortified, and are divided into two groups based on occupational age.

1) Fortified sites built on unmoated sites (village to urban); this group is generally richer in surface and subsurface pottery sherds than the second group.

2) Fortified sites built on unoccupied sites (urban center resulting from selection a suitable site)

The floodplain or terrace division is then used to generate a chronology of moated sites, with simple sites on the lower floodplain gradually developing into chiefdom. The protohistoric period sites had been founded on the low terraces, where, by the 6th century CE, they were considerably influenced by the kingdom of Chenla (Vallibhotama 1984).

Welch’s study of the Phimai region identified three site types based on height and quantity of earthworks and moats (Welch 1985).

1) Fortified sites with multiple earthworks or walls over 2 m high, implying a defensive function

2) Ponded sites with small earthworks and scatters encircling ponds

3) Ordinary habitation sites

Welch (1985) found fortification of upland sites in Phimai region were more common than alluvial plain sites which resembled the results study of sites in the Mun river by Moore (1986). He found no strong correlation between earthwork complexity and site size. However, Moore (1986) stated that earthwork complexity was not necessarily defensive as the word fortified implies. Instead, the increasing of the earthwork indicates an increased need for water preservation on terrace regions. Furthermore, the moated site developed on the terraces because it was a successive result from the construction of more extensive earthworks.

2.1.2.3 Limitation of Data on Dvāravatī Sites

Over several decades, various individuals and institutions have studied and discovered a large number of Dvāravatī sites across the country, especially in the Central Plain and Northeast regions. However, at present, many of these sites have not been investigated in detail and accurate numbers of these sites have not been systematically presented. Supajanya and Vanasin (1980) presented 63 ancient sites distributed in Lower Chao Phraya Plain by using aerial photographs. Most of these sites belong to Dvāravatī period (see detail in Vanasin and Supajanya1980). Additionally, during 1981-1984, Supajanya and Vanasin presented the study in “The Inventory of Ancient Settlements in Thailand” by using aerial photography of scale 1: 15,000. They identify approximately 1,300 ancient cites across the country and 900 sites surrounded by moats (Supajanya 1986; Supajanya and Vanasin 1984). However, the age of these moated sites has not been identified and some are being destroyed. Mudar (1993) continued her study based on Vanasin and Supajanya’s 63 sites and also discovered new sites (see also Mudar 1993 and 1999). Indrawooth (1999) lists 47 sites across the country (see also Indrawooth 1999: Map 7). Pisnupong (1999) studied Dvāravatī sites in Central Plain and presented 55 ancient towns (cities) and 55 ancient communities (Pisnupong 1999). Gallon (2013) identified 32 moated sites, 2 unmoated sites, and 9 unlocated sites or unassessed in satellite imagery based on Indrawooth (1999: Map 7). Murphy (2010) lists 93 Sema sites in Northeast Thailand (see also Murphy 2010: Table A1b). On the website of the Fine Arts Department (FAD), more than one hundred relevant Dvāravatī period sites are listed, but these sites included a variety of sites such as artifact scatters, monuments, religious sites, quarries, and so forth (see detail at http://gis.finearts.go.th/fineart/). Another source is Princess Maha Chakri Sirindhorn Anthropology Centre (SAC) which provides a searchable web service for Dvāravatī sites (http://sac.or.th/databases/archaeology/สมัย–วัฒนธรรม/สมัยทวารวดี.).

In this research, Dvāravatī sites from accessible resources were gathered and categorized based on their functions and purposes (see Appendix D). Overall there are 425 sites used in this research.

2.1.3 Socio-Political Aspect

Several scholars have studied the process of urbanization of Dvāravatī culture as reflected in site layouts. For example, Wales (1969) tried to construct a chronology of it evolution over time from more irregular–shaped plans, which indicated as growing out of Iron Age precedents, to more regular plans affected by urban planning ideas from Indian culture. Gallon (2013) argued that the chronology of these moats is uncertain at most sites. Consequently, it is impossible at this point to develop a clear timeline for layout development (Murphy 2016). Gallon (2013) categorizes six site types ranging from irregular to rectangular, but did not see a linear development. Instead these sites coexist and overlap in time. Most of moated-sites shapes are either semi-rectangular or rectangular. For instance, Si Thep has an extension layer added later. Other consistent features comprise religious architecture in brick, laterite or a combination of both. Large–scale stupas exist at sites such as Nakhon Pathom and Si Thep, while other monastic constructions such as assembly and ordination halls have been found at Mueang Sema and Mueang Fa Daed (Murphy 2016).

Gallon's doctoral study at the moated site of Kamphaeng Saen aims to provide a better understanding of urbanization during the Dvāravatī period. Kamphaeng Saen is located roughly equidistant between Nakhon Pathom and U Thong; it is a smaller–scale site and may have served as a satellite settlement of these two cities (Gallon 2013). The discovery of a Dharmacakra, its inscribed socle, and three Buddha images provides evidence for the adoption of Buddhism. The results of AMS radiocarbon dates obtained from excavations specify that the site was begun in the early 5th century and declined a few centuries later (Gallon 2013). The most intensive phase of occupation was from the 5th–6th centuries to the mid–7th century, with the site being abandoned by the 9th century (Gallon 2013).

Gallon (2013) proposed the model of peer–polity interaction to describe the Dvāravatī political aspect since there is limited evidence of Dvāravatī socio–political organization. The model is based on the widely shared material culture and multiple centers of political power apparent during the early Dvāravatī period (Gallon 2013). The Dharmacakras, identified by Brown (1996), may signify the importance of imitation and competition among the rulers of the peer polities (Gallon 2013). The earthworks surrounding many Dvāravatī sites suggest that warfare, or at least its threat, was also a common feature in their interaction. The early multiple centers possibly represent peer polities that were at some point united under a single kingdom centered at Nakhon Pathom (Gallon 2013).

Mudar's (1999) study of Dvāravatī settlement patterns in the Central Plain provided an initial idea of the boundaries of the peer polities (Gallon 2013). Using aerial photographs of moated sites collected by Vanasin and Supajanya (1980), she examined the site–size hierarchy of Dvāravatī moated sites in the Chao Phraya River Valley. Mudar concluded that by the end of the Dvāravatī period, these settlement patterns were organized into a single centralized state. She classified a settlement hierarchy of at least six tiers. Nakhon Pathom is the only site falling into top tier which is defined as a 'primary center'. Suphan Buri and Praaksrigacha/Sankburi fall into the second tier. Mudar used each site's population and their rice growing areas to identify several regional centers. She identified four levels of administrative hierarchy, with Nakhon Pathom again falling into the top tier,as a 'supra–regional center'. U Thong falls into the third level as a 'district center'. Her study indicates interdependence between the sites of central Thailand during the Dvāravatī period. She notes that in the early stages of the Dvāravatī period there may have been smaller–scale competing polities in the Chao Phraya Basin, but presently there are limitations in the archaeological evidence to confirm whether there was unified control or state–level society. Mudar also noted the limitations of her dataset since she assumed that all Dvāravatī sites were contemporaneous (Mudar 1999). Her study did not include Si Thep (approx. 4.69 km^2 in area), which is located along the Pasak River Valley at the interface between the Khorat Plateau and the Central Valley. Si Thep is larger than all of the sites in Mudar's sample except for Nakhon Pathom (Gallon 2013). Mudar (1999) notes that Dvāravatī settlements fit the definition of peer polities (Renfrew 1975) since they are approximately the same size and show a shared system of writing, beliefs, language, and political institutions (see Mudar 1999). She indicates that by the end of Dvāravatī period, there was a center based around Nakhon Pathom from 9th to 10th century onwards. However, political power and influence could have shifted over time; for instance, U Thong emerged in the 7th century and declined later (Murphy 2016). Mudar (1999) specifies that there was no centralized Dvāravatī state before at least the 7th century CE and possibly much later (Murphy 2016). Therefore, the 4th to 6th centuries CE may be considered as a proto–Dvāravatī period. These Dvāravatī sites were most possibly interacting with each other, while they were also developing largely independently (Murphy 2016).

Kealhofer and Grave (2008) presented an analysis of environmental modification and its relationship to urbanization in central Thailand (Kealhofer and Grave 2008). Using the cores collected from a roughly 30 km^2 study area surrounding the 1st to 2nd millennium CE walled settlement of Kamphaeng Phet, they found evidence of the replacement of forest by agricultural activity. They noted that minor cultural changes to the environment were already happening in the early Holocene (Kealhofer and Grave 2008). An agricultural landscape was formed across the region at least 5,000 years prior to the historical development of Kamphaeng Phet. The landscape is shown initially as a mixture of slash and burn and rice agriculture, followed by numerous distinguishing cycles of intensification, particularly from ca. 2,200-1,700 BP and from ca. 1,000-500 BP. The spatial development of this change specifies using of Ping River water for wet rice agriculture, with a slow extension of canals to the southeast. This chronology indicates population increase, agricultural intensification and diversification occurred prior to the start of urban development and growing political complexity in the Dvāravatī period (Kealhofer and Grave 2008).

2.2 Dharmacakra

The earliest representation of the Buddha's teaching is believed to be the Dharmacakra (Sanskrit *Dharmacakra*, Pāli *Dhammacakka*) established by Emperor Asoka, an Indian emperor of the Mauryan dynasty (4th to 2nd BCE) in the Deer Park at Sarnath near Benares, India, on the site of the Buddha's first sermon or the *Dhammacakkappavattana sutta* (first turning of the Wheel of the Law) (Lyons 1979; Murphy 2013a; Wales 1969). The initial evidence shows that Dharmacakra was carved to represent the first sermon of Lord Buddha, which was normally used when the Buddha was not yet portrayed in form of human (Assavavirulhakarn 2010). Thus, the Buddha and the group of the first five monks were not traditionally shown. For instance, at Sanchi gateway (3rd century BCE), Buddha's first sermon is depicted by a wheel sided by a group of deer (Figure 2.12) (Murphy 2013a). The wheel was accepted as the most appropriate symbol of Buddhism, both in physical and religious aspects (Murphy 2013a). Afterward, Buddha images became commonly accepted (Murphy 2013a; Yupho 1990). During the Dvāravatī period, together with the Buddha images, Dharmacakra with crouched deer was normally found (Murphy 2013a; Yupho 1990). Dharmacakra appears very early in India. It is shown on the column of Asoka, on the pillars of Sanchi, and is frequently shown in Amaravati reliefs. The concept possibly came to

Thailand by way of a votive tablet having a representation of the wheel at a holy place, or by a small replica (Lyons 1979). The Dharmacakra tradition prospered throughout the Amaravati period but vanished during Gupta and subsequent eras and from India around the 3rd or 4th century CE. Few freestanding Dharmacakras still remain in India (Assavavirulhakarn 2010:67).

Figure 2.12: Bas–relief at Sanchi gateway in Raisen district of the state of Madhya Pradesh, India (Digital Image. Retrieved April 22, 2017, from http://historum.com/asian–history/60795–early–buddhism–brahmanism.html.)

Dharmacakra was emphasized as the connection between Southeast Asia and India. The designs of Dharmacakras found in India belong to Gupta period (320–600 CE) (Brown 1996). However, the traditional style of Dharmacakras can be traced back to as old tradition as Mauryan era (4th to 2nd BCE) which was introduced to this region as early as the 4th century CE (Assavavirulhakarn 2010; Ito 1979). Dharmacakra was developed tremendously in the period with the Theravada sect of Buddhism around 7th century CE in central Thailand (Krairiksh 2012). Brown (1996) noted that Dharmacakras would have not been dated before the 7th century CE, probably not until 650 CE (1981:287). The Dharmacakra provides the clearest evidence for the presence of the Theravada school within the Hinayana lineage at this time (Krairiksh 2012). The Pāli inscriptions, which are found either on the wheels or on pillars, were quoted directly from the Tipitaka (the Pāli Cannon) (Saraya 1999). Since the teaching at the core of Buddhism is too difficult for ordinary people to understand, Dharmacakras may have been adopted by the ruling class with specific purposes such as being used to declare the sacred or supernatural power of rulers (Saraya 1999).

In addition, Dharmacakra may have been developed as an integration of religion and doctrine to foster kingship as Cakravarti Raja concept. The idea of Cakravartin (Sanskrit *cakravartin*, Pāli *cakkavattin*) signifies that the cakra or wheel (symbol of sovereignty) of the emperor's chariot can roll everywhere without obstacle (Indrawooth 2008b). Only the Universal Monarch who was accepted as the Cakravarti Raja or Dharma Raja (the King of essential purity of Justice) can turn the Wheel of the Law, which is similar to the Buddha who turns the Wheel of Dharma (Brown 1996; Indrawooth 2008a; Saraya 1999; Yupho 1990). The motifs on Dharmacakra specify the prosperity and fertility of land (Saraya 1999). Cakravarti Raja is the determining component of cosmic change, the climate, and the fertility of the kingdom (Saraya 1999).

Due to these observations, the study of the Dharmacakras' distribution and Dvāravatī settlement patterns as well as the motifs on the wheels might indicate the geographical landscape or environmental condition during Dvāravatī period. Presently, no evidence of a massive defensive structure exists in the Dvāravatī period which might suggest that the rulers adopted this Cakravarti Raja concept together with Buddhism to peacefully rule the kingdom. In this aspect, instead of building a massive wall to protect the kingdom, the rulers might employ Dharmacakra as a symbol of the kingdom boundary, the power of rulers, or even served as national flag to signify the kingdom, or served as the center of the community. At this point, the variation in sizes, motifs, and scriptures on the wheels may signify some meaning.

2.2.1 Dharmacakra in Thailand

It is thought that Dharmacakras in Thailand were adopted during the reign of the Indian Emperor Asoka, Mauryan period. Literally, Emperor Asoka ordered the high–ranked monks, Sona and Uttara, to disseminate the teaching of the Buddha in Suvanabhumi (Department 2009). The center of Suvanabhumi remains ambiguous (see also Assavavirulhakarn 2010). Primarily, it is believed that Dvāravatī people had become Buddhists since the reign of Emperor Asoka. However, all the archaeological findings, including the motifs on the wheels which obtained from Gupta art, indicated that Dvāravatī received the Buddhist religion after the 3rd or the 5th century CE (Department 2009). Numerous Dharmacakras found in Dvāravatī period, the style cannot be dated earlier than the Gupta period which rooted in this region no later than the 4th Century CE (Assavavirulhakarn 2010:67).

Beside Buddha images, Dharmacakras have been discovered from major Dvāravatī sites in central Thailand and in other regions where Dvāravatī culture extended (Indrawooth 2008b). These sites include Haripunjaya in the northern region; the Muang Sema, Fa Daed, and Na Dune in northeastern region; and Chaiya and Yarang in the southern region (Indrawooth 2008a). Indrawooth (2008a:34) suggested that the Dharmacakras indicated that the Dvāravatī kings followed Buddhist practice as recorded in *Cakkavatisihanāda Sutta* and as practiced by Asoka. The concept of dual kingship model, Bodhisattva as cakravartin would highlight the practice of Dharma as leading toward enlightenment and to help other to attain enlightenment (Indorf 2013). Dharmacakras address specific aspects of enlightenment as represented by their inscriptions and ornament (Indrawooth 2008a:29-33, Indorf 2013:227). For instance, the Pallava inscriptions (7th century CE) appear on some Dharmacakras' parts such as spoke that were discovered form major sites such as Nakhon Pathom, Lop Buri, and Chai Nat provinces (Indrawooth 2008a:24). These inscriptions mostly contain the extracted texts from Pāli cannon such as the Four Noble Truths, *Paṭiccasamuppāda* (the Law of Dependent Origination), *Dhammacakkappavattana Sutta* (Setting the Wheel of Dhamma in Motion), and the *ye dharmā* stanza (Indrawooth 2008a:24). The Dharmacakra and the *ye dharmā* stanza that found over the area are a continuance of tradition that existed in India since the 1st Century CE (Assavavirulhakarn 2010).

The first discovery of the Wheel of the Law in Thailand occurred in the reign of King Rama IV (1851–1863 CE). When His Majesty commanded that the Phra Pathom Chedi at Nakhon Pathom province be repaired, many stone Wheels of the Law were found in the compound (Yupho 1990). The Dharmacakras were usually found with the deer figures (Figure 2.13).

Figure 2.13: Dharmacakra and deer found in Nakhon Pathom Province, exhibited at Bangkok Nation Museum (Photo by Areerut Patnukao)

2.2.2 Motifs and Categories

The Dharmacakras consist of two–to–three distinct parts (Figure 2.14a). Firstly, the cakra/wheel itself is shown with spokes radiating out from the center to the rim (Figure2.14a-1). The number of spokes vary between 8 to 36, and some of the wheels do not have the same number of spokes on both sides (Yupho 1990). Secondary, the socle is the square base beneath the wheel which is used to fix the wheel onto pillar (Figure2.14a-2). Thirdly, the stambha (pillar) supports of the wheel (Figure2.14a-3) (Murphy 2010).

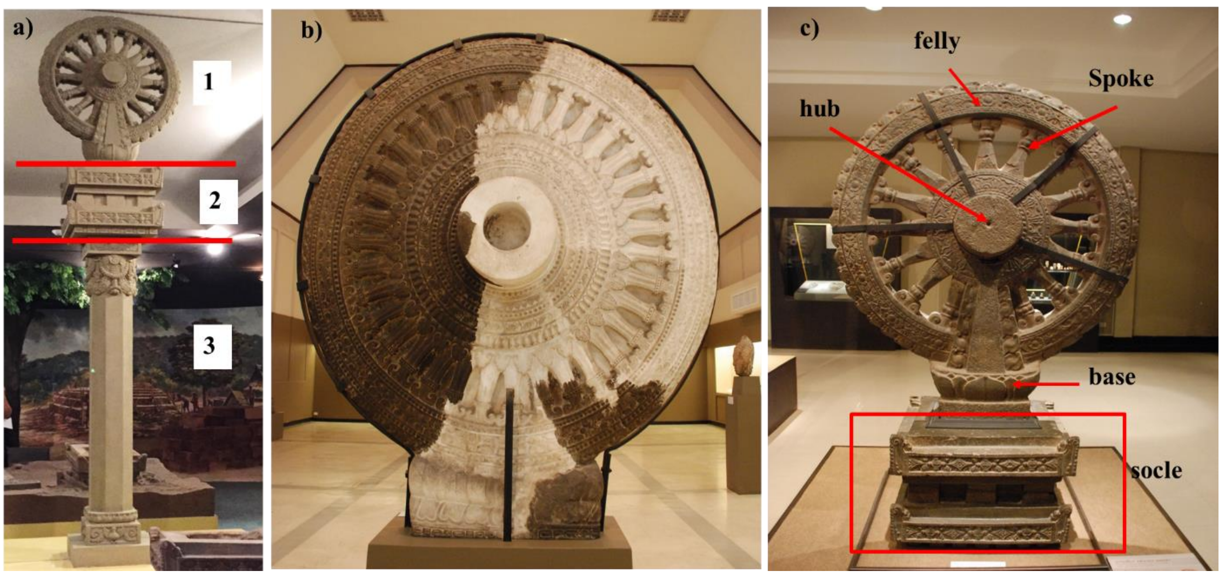


Figure 2.14: a) three major parts of Dharmacakra, U Thong National Museum; b) the currently largest Dharmacakra, Bangkok National Museum; c) Dharmacakra's elements, Stūpa No. 11, U Thong (Photo by Areerut Patnukao)

In Thailand, Dharmacakras are found in various sizes. The largest one is currently exhibited at the National Museum in Bangkok (2 m in diameter) (Figure 2.14b). Some motifs appearing on the spoke, the rim/felly, the hub, and the foundation stand/base of the wheel (Figure 2.14c) are derived from Gupta art (Yupho 1990). In some wheels, the spaces between the spokes are cut through and some are not. The wheel stand/base is sometimes engraved with lotus designs or with other designs. Most of the Dharmacakras are made from one kind of stone called argillite (Indrawooth 2008a). A few wheels are carved from laterite, slate, sandstone, or are made of terra-cotta. The wasted stone flakes, unfinished Dharmacakras, and deer figures, were found at the stone workshop in Khao Yoi district, and Ban Lard district, Phetchaburi province (Indrawooth 2008a; Silapanth 2006).

In addition to crafted stone sculptures, Dharmacakra symbols have been found in other materials, such as low relief on a stone boundary found at Ban Bua Semaram in Buriram province (Figure 2.15a); Buddha’s footprints found at Sa Morakot site in Prachinburi province (Figure 2.15b); an embossed gold plate found at Si Thep site in Phetchabun province (Figure 2.15c); and a votive tablet found at Ku Bua in Ratchaburi province (Figure 2.15d). However, this study mainly focuses only on stone Dharmacakras.

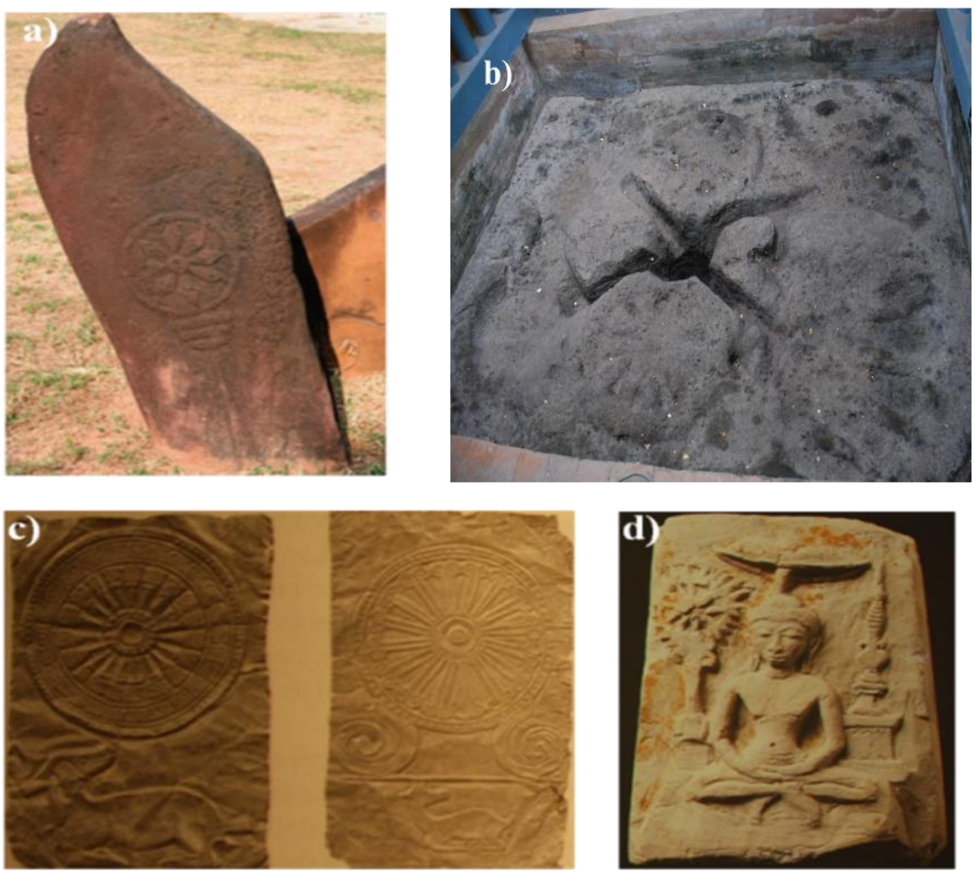


Figure 2.15: a) Low relief on stone boundary found at Ban Bua Semaram in Buriram province (Murphy 2010:329–330), b) Buddha’s footprints found at Sa Morakot site in Prachinburi province (Photo by Areerut Patnukao), c) an embossed gold plate found at Si Thep site in Phetchabun province (Saraya 1999:202), d) votive tablet found at Ku Bua in Ratchaburi province (Department 2009:75)

Dharmacakras have been categorized by several scholars. Based on the elements in decorative motifs, Wales divided Dharmacakras into four types (Wales 1969). Type 1 is the first and earliest developed pattern. It has a wide, perfectly delineated band of decoration on both sides of the rim showing the alternating lozenges and lotus motif which are of late Gupta derivation and characteristic of the earliest known Dvāravatī style of ornament (Figure 2.16a). Type 2 shows a degeneration of the alternating lozenge and lotus flower motifs on the wide ornamental band on the rim. There is a very definite row of beading on both sides of this band and the row of lotus petals around the hub is similarly bordered either on the inside or on both sides (Figure 2.16b). Type 3 is characterized by the replacement of the lozenge and lotus design on the wide band of the rim by a distinct vegetal motif. The beading is usually fine marked (Figure 2.16c). Type 4 is characterized by simplification. The rim is simply decorated by rows of beading on both sides (Figure 2.16d) (Brown 1996; Indrawooth 2008b; Wales 1969).

Brown (1996) categorized Dharmacakras into six groups based on an analysis of patterns: 1) lozenge-and-circle pattern, 2) volutes-and-circle pattern, 3) rinceau pattern, 4) idiosyncratic patterns, 5) plain fellies, and 6) Hindu cakra related types (Figure 2.17).

Saisingha (2000) divided Dharmacakras into three types due to designs. Type 1 is similar to Wales' Type 1. Type 2 is the most common type, showing a lotus or another kind of flower motif on the base of the wheel. Type 3 is depicted by adding deity or people figures on the base of the wheel (Saisingha 2000).

Figure 2.16: Wales's (1969) categories: a) Type 1 displayed at Bangkok National Museum (CBB1); b) Type 2 displayed at Phra Pathom Chedi National Museum (CNP1); c) Type 3 displayed at Phra Pathom Chedi National Museum (CNP4); d) Type 4 displayed at Phra Pathom Chedi National Museum (CNP5)

Indorf (2014) continued Brown's (1996) work and characterized Dharmacakras into four types based on base element motifs and felly patterns. Types 1 is the Funan style: relatively plain (Brown's group 6), sometimes with beads or a thickened felly base (base types 1B, 1C, or2B). Type 2 is the Khmer style: felly band ornamentation with lozenge and floral motifs linked by a central line parallel to the band edges (Brown's group 1); if base elements are present, they are male symbols of energy (base types 1B, 1C, 2A, or 2B). Type 3 is the Mon style: felly band ornament with only beads and/or foliage motifs including spirals (Brown's groups 2,4 and 5); when base elements are present, they represent female symbols of energy (base types 1A, 1B, or 3A). Type 4 is the Mon–Khmer mixed style: combining or mixing of Mon and Khmer elements (Indorf 2014:290) (Figure 2.18).

In addition, Indorf classifies base elements into three groups. 1) Natural bases, those in which the felly continues around the whole perimeter: 1A = with a lotus below the felly; 1B = without a lotus below the felly; 1C= with only a raised rectangle on the felly. 2) Male base elements: 2A= a tapered or triangulated flame column; 2B = a figure of Sūrya or a Kala face. 3) Base elements which reflects a female energy: 3A = non-figural, floral *śrī* stele; 3B= with figure (Indorf 2014:290). In this study, the relationship between the spatial distribution of these Dharmacakras and their motifs were based on classifications of Brown (1996) and Indorf (2014).

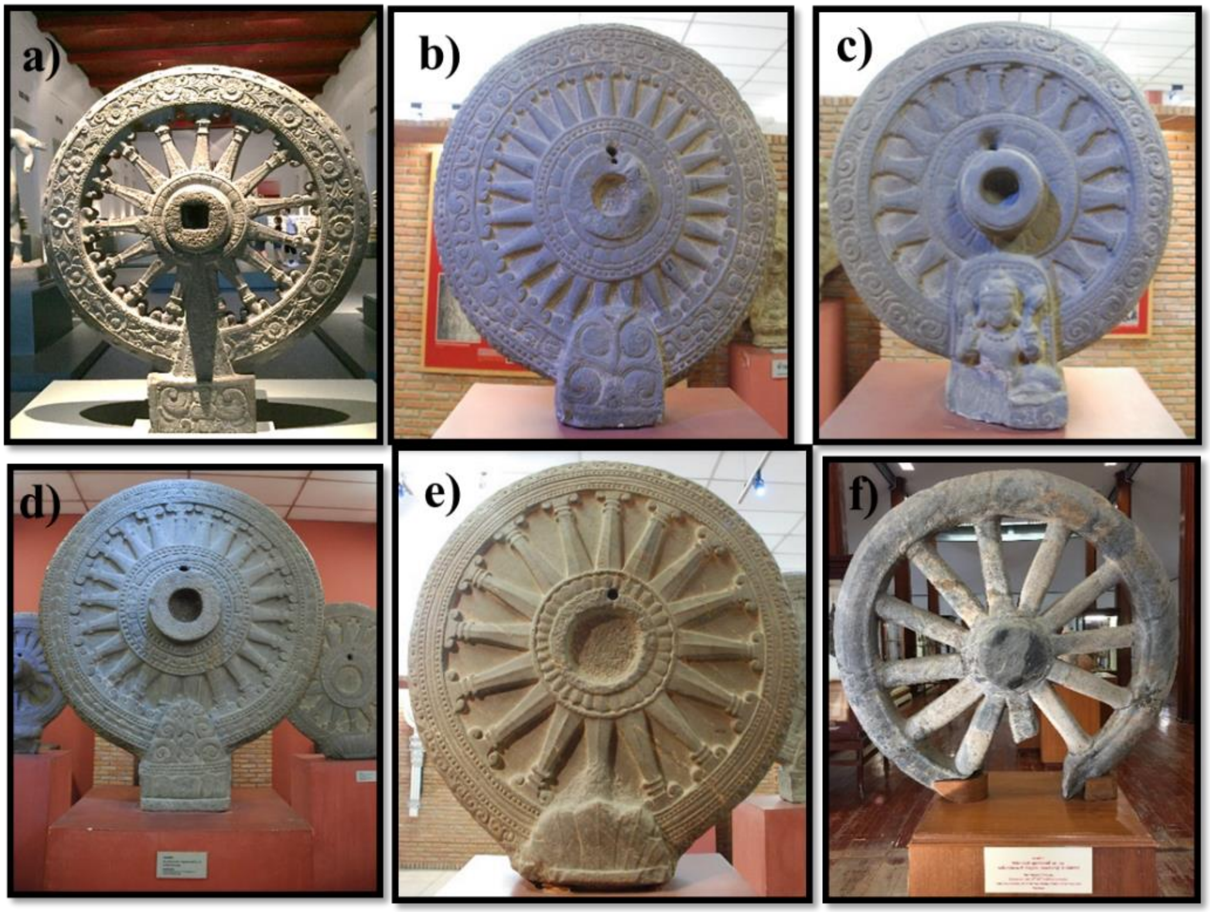


Figure 2.17: Brown's (1996) categories: a) Type 1 displayed at Bangkok National Museum (CBB1); b) Type 2 displayed at Phra Pathom Chedi National Museum (CNP6); c) Type 3 displayed at Phra Pathom Chedi National Museum (CNP4); d) Type 4 displayed at Phra Pathom Chedi National Museum (CNP3); e) Type 5 displayed at Phra Pathom Chedi National Museum (CNP7); f) Type 6 displayed at In Buri National Museum (CSI1)

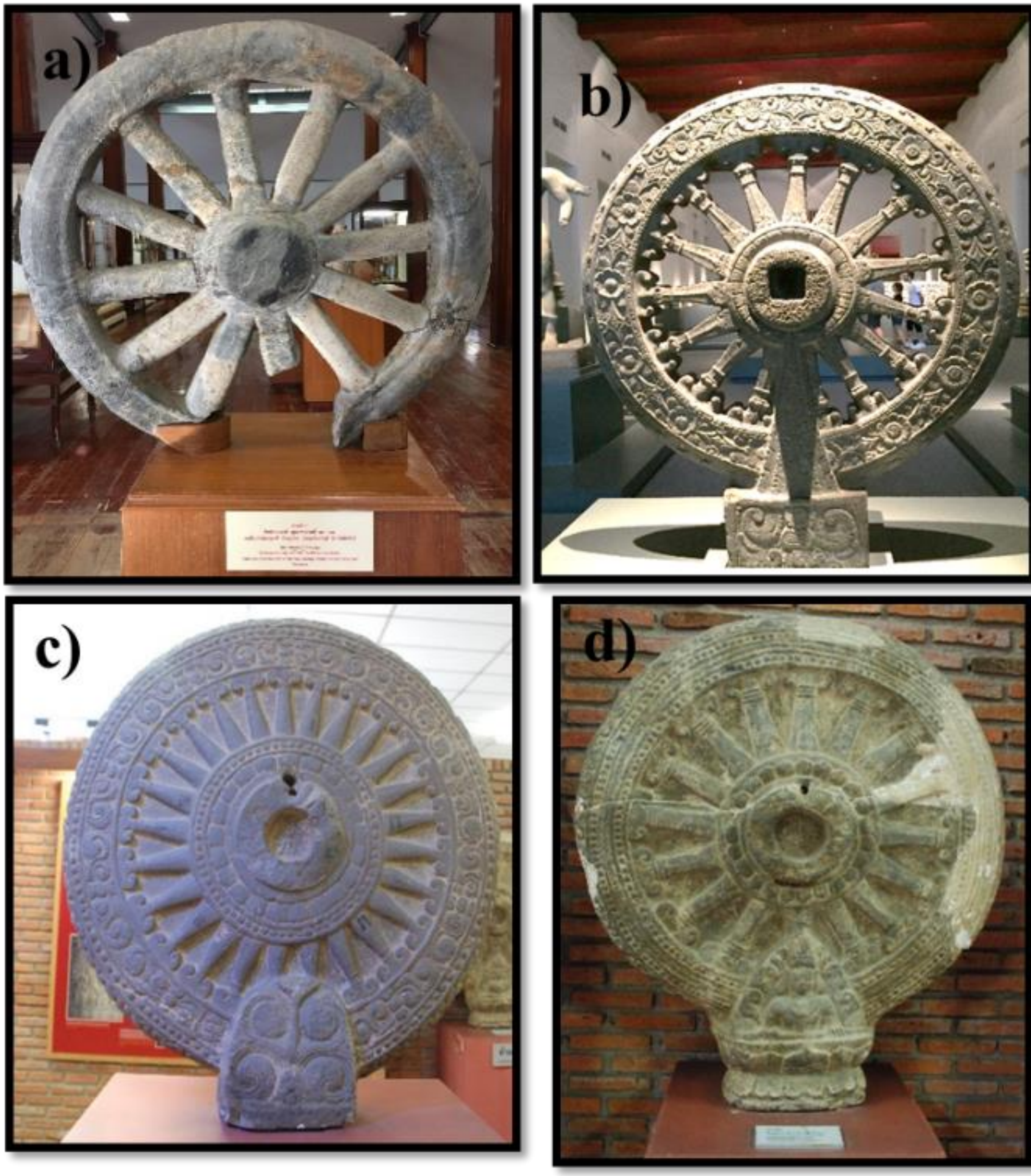


Figure 2.18: Indorf's (2014) categories: a) Type 1 displayed at In Buri National Museum (CSI1); Type 2 displayed at Bangkok National Museum (CBB1); c) Type 3 displayed at Phra Pathom Chedi National Museum (CNP6); d) Type 4 displayed at Phra Pathom Chedi National Museum (CNP5)

2.3 Environmental Setting

Thailand is located in mainland Southeast Asia between latitudes 5° 37’ N and 20° 27’ N and longitudes 97° 22’ E and 105° 37’ E. It covers an area of 513,115 square kilometers. It is bordered by Myanmar in the west and northwest, Laos to the northeast, Cambodia to the southeast, and Malaysia in the south (Figure 2.19).

2.3.1 Geographic Regions

The area of Thailand is over half million square kilometers, or roughly the same size as France. It is second only to Myanmar in size among mainland countries of Southeast Asia. Almost two–thirds of the area of Thailand is mountainous or hilly, the rest is flat and utilized for residential and other purposes (Bank 2011). Based on topography, ecology, and geology, Thailand can be categorized into six geographic regions: Central Plain, West, North, Northeast, East, and South (Figure 2.1). The Gulf of Thailand is located completely on the continental shelf with less than a hundred meter in water depth (Pendleton 1962).

Central Plain

The Central Plain forms the broad center of Thailand, which is crossed by a network of rivers and canals which flow into the country’s main river, Chao Phraya. Although largely an alluvial plain, inliers of older bedrock occur around the margin of the plain. The Central Plain is intensively farmed and is the rice–bowl of Thailand (Ridd, et al. 2011). This region has the highest population density and most fertile agricultural land. The Chao Phraya River, its broad alluvial plain, and several distributaries form the lower part of the region. The upper part includes the Chao Phraya’s tributaries and their surrounding valleys. From the northern tributary valleys to the Chao Phraya’s mouth at the Gulf of Thailand, the Central Valley covers approximately 480 km from north to south and about half that distance from east to west (Pendleton 1962). The relief is normally level or nearly sea level, but becomes undulating along the inland borders of the region. A distinctive microrelief is raised formed by natural levees along the main rivers, tributaries, and distributaries (FAO/UNESCO 1979).

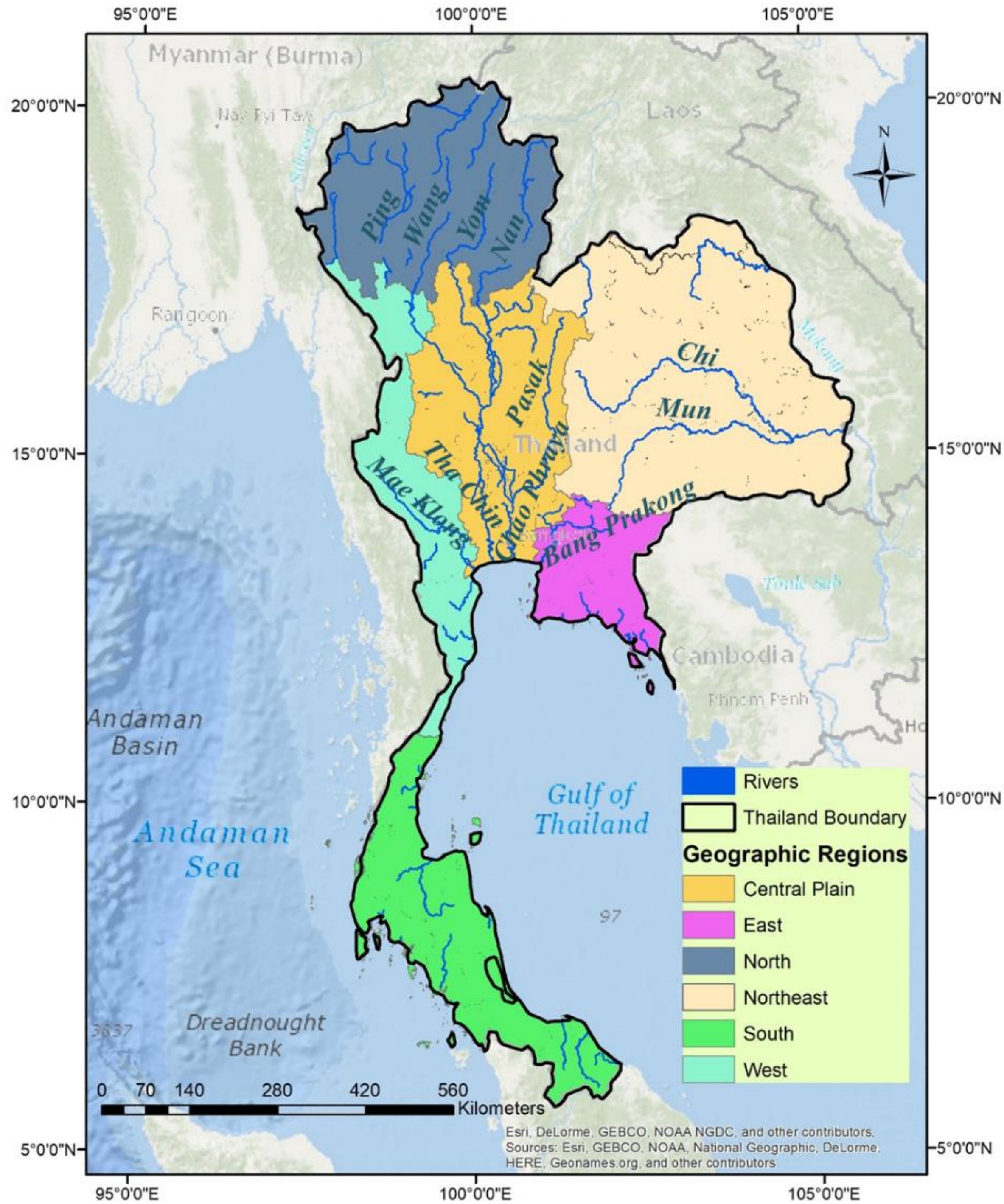


Figure 2.19: Geographic Regions of Thailand, map by Areerut Patnukao, basemap from Esri, USGS, NOAA, and other contributors

The Ping, Wang, Yom, and Nan rivers meet to form the Chao Phraya river at Nakhon Sawan province. The Chao Phraya river has developed meander belts which has developed several geographic features behind when it laterally migrated, for instance, point bars, floodplains, oxbow lakes, meander scars, and levees (Sinsakul 2000). The main part of the Chao Phraya delta is tide dominated. Delta growth is caused by the movement of tide in and out of the channel and over the old delta plain (Sinsakul 2000). The Mae Klong, Tha Chin, and Bang Prakong rivers also drain to the Gulf of Thailand. These rivers have supplied the Lower Central Plain with rich deposits of silt. Lower Central Plain has an average elevation of 2 m above MSL (Sinsakul 2000). The northern marginal of Central Plains contains foothills that rise to the Tenasserim range in the west and the Khorat Plateau and Phetchabun Mountains in the east. The rock outcrops, alluvial fans, and old river terraces topped by thick deposits of laterite are main topographic features (Sinsakul 2000).

West

The western region, which covers the southern extension of the western highlands running parallel to Myanmar border, is mountainous. The Tenasserim range is the westernmost ridge. It begins at Three Pagodas Pass along the Thai-Myanmar border and extends southward into peninsula of Thailand (Pendleton 1962). The peaks are mostly between 1,000 and 2,000 m like other places in the country (Ridd, et al. 2011). Khao Kha Khaeng, at 2,152 m in the northern part of the region, is the highest granite mountain peak. Other rocks are sediments of mostly Palaeozoic and Mesozoic age. The topography arranges in NW-SE direction which indicates the regional strike and trend of the main faults, including the Three Pagodas Faults and its various slopes. Oil shale can be found at a fault-bounded Cenozoic intermontane plain on the Myanmar border in Mae Sot district (Ridd, et al. 2011). The mountains in this region are the watershed of several tributaries of Chao Phraya, Salween, and Mae Klong rivers (Pendleton 1962).

North

Northern Thailand is a region of parallel mountain ranges with steep valleys and several peaks over 2,000 m high. Thailand's highest peak, Doi Inthanon (2,565 m), is located around 60 km southwest of Chiang Mai. Ping, Wang, Yom, and Nan rivers, which drain southward to form Chao Phraya river, are created along these ranges (Pendleton 1962). The southwest of the region is an extensive area of Paleozoic and Triassic sedimentary and volcanic rocks (Ridd, et al. 2011). The development of the mountains' relief in northern Thailand has occurred under the influence of two different bases of erosion. The Mekong River shapes the base level for the northern part while the Chao Phraya river basin erodes the areas in the south (Pendleton 1962).

Northeast

The Northeast is dominated by the Khorat Plateau. This plateau is mostly a low-topography feature, underlain by 3,000–4,000 m of subhorizontal Mesozoic continental clastics of the Khorat Group. In some areas, especially the western edge of the plateau and around the Phu Phan uplift, the Khorat Group has been modified by Cenozoic folds and gives rise to a mountainous topography. The plateau is isostatically uncompensated today, which required further regional uplift before the region is entirely compensated (Morley, et al. 2011). An undulating plain is formed of slightly folded upper Mesozoic non–marine sediments with rowing red–beds. Elevations are normally less than 250 m. The western and southern edges of the plateau are formed of inward–dipping forests of Mesozoic sandstone with 1,000 m above MSL in some places. The uppermost Mesozoic beds consist of the Maha Sarakham Formation overlain by the Phu Thok Formation sandstone (Ridd, et al. 2011). The northeast is the most infertile region of the country. The mixture of a long dry season and poor soils is difficult to cultivate. Large areas are flooded during rainy season, but they are drought in dry season. In most parts of the region, soils are thin and poor

(Pendleton 1962). Arable land is restricted to dispersed alluvial plains around Mun, Chi, and Mekong Rivers, and their tributaries. This region is separated from the rest of the country by high mountain ranges, the Phetchabun and Dong Phrayayen in the west, and the Sankamphaeng and Phnom Dong Rak in the south (Supajanya and Vallibhotama 1972).

East

This region is located between the Khorat Plateau and the sea. Its topography is dominated by granite intrusions and other crystalline rocks. The highest peak is Khao Soi Dao (1,670 m), around 30 km from the Cambodian border (Ridd, et al. 2011). The region is bordered on the north by hills and mountains along the southern edge of the Prachin river valley, on the west and south by the Gulf of Thailand, and on the east by range of flat-topped hills, the Banthat range, which marks the Thailand-Cambodia border. The southeast coast region includes a well-dissected upland in the northern and central parts, and a coastal plain in the south and west. Several streams are mostly drained in a southern direction (Pendleton 1962). Most of relief is caused by strongly folded Palaeozoic and Triassic sedimentary, metamorphic, and volcanic rocks. Several small islands spread off the northern part of east coast, and are formed largely of metamorphosed Paleozoic rocks. The two largest islands arise in the southeast of the region, close to the border with Cambodia. The larger, Ko Chang, is formed of Permo–Triassic volcanic rocks while the other, Ho Kut, is formed of gently folded upper Mesozoic non–marine sandstone and mudstone like that of the Khorat Plateau. These outcrops are the western rim of a Mesozoic basin which extends into Cambodia. Olivine basalt flows of Cenozoic age are commercially most significant in this region (Ridd, et al. 2011).

South

The South of Thailand is a peninsular area which covers about 84,000 square kilometers in a narrow north–south strip. The land varies in width from 16 to 220 km. The plains form along coastal areas and highlands form along the backbone of the Peninsula. Mountains extended from the north to south. Small plains or valleys are located between these mountains. Peninsula East Coast and the Peninsula West are physically different (Pendleton 1962). The Peninsula East Coast is smooth and regular with few bays, but long beaches. The coastal plain is about 5–35 km wide, and there are several river plains and basins which broaden far inland. The north of Songkhla province situates large inland sea, Songkhla Lake (Pendleton 1962). On the other hand, the west coast of the peninsula is a hilly strip of narrow highlands uplifted due to Late Cenozoic tectonic processes forcing subsidence in the Andaman Sea area to the west and the Gulf of Thailand to the east. Along the Thailand–Myanmar border lies the Tenasserim range which runs from north–northeast to south–southwest. The west-coast coastline is very irregular and much indented with estuaries (Morley, et al. 2011).

2.3.2 Geology

Thailand is situated at the east rim of one of the world's major structural zones, Eurasian Plate (Figure 2.20). From northwestern Thailand, the zone extends northward through northeastern Myanmar and the Yunnan province of southern China and continues westward through Tibet as the Himalaya mountain chain. From northwestern Thailand and northeastern Myanmar, the zone spreads southward as two parallel units. The first one runs through western Myanmar and the Andaman Islands, curves southeastward through Sumatra, and continues eastward through Java and the Lesser Sunda Islands. The second one runs southward through Peninsular Thailand and the Malay Peninsula and curves eastward through the northern islands of Indonesia. The facies distributions in sedimentary rocks, igneous rocks, fault and fold in the western zone of Thailand indicates the recurrent tectonic activity back into the Paleozoic Era (Shawe 1984).

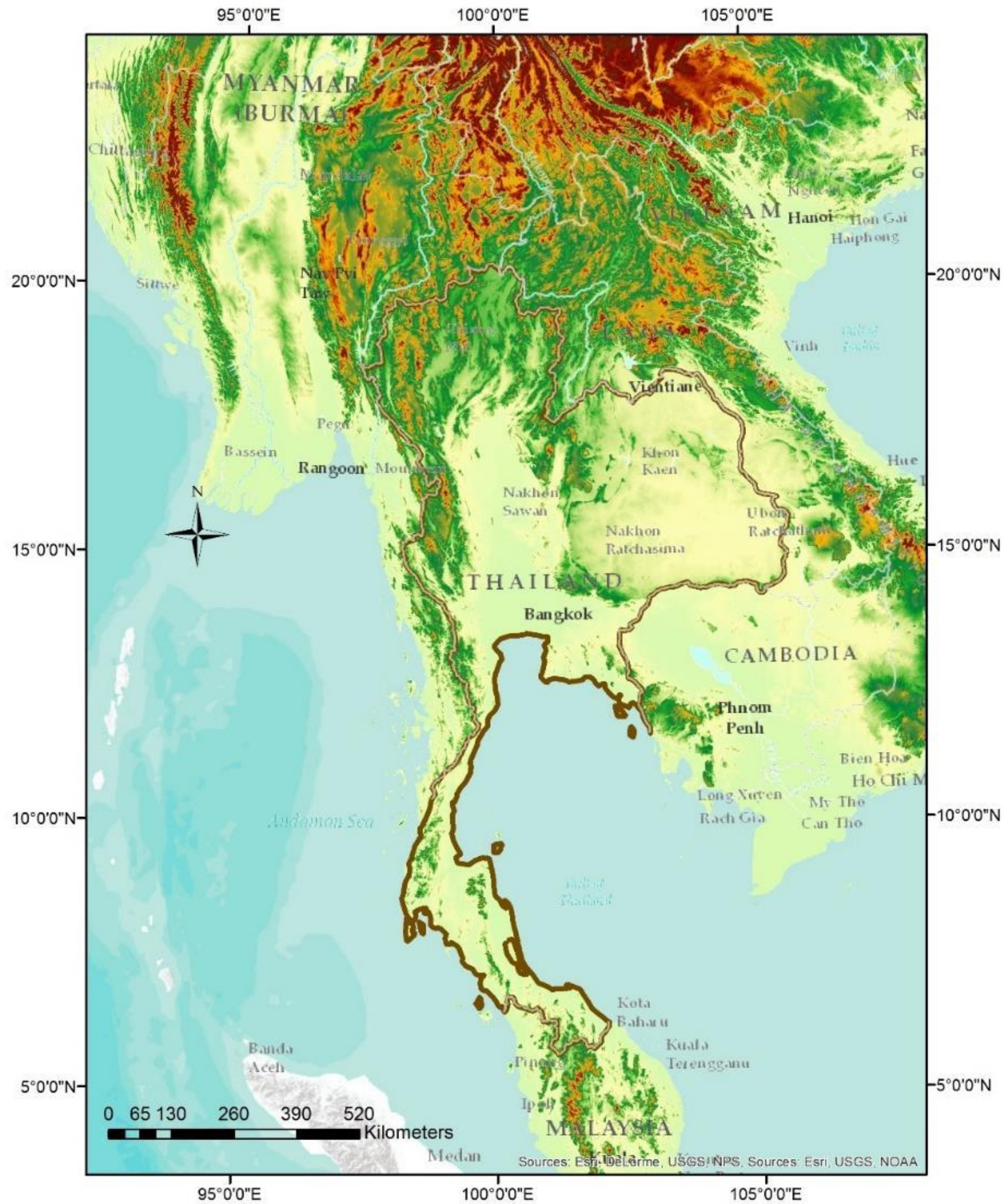


Figure 2.20: Map of Thailand and neighboring countries, map by Areerut Patnukao, basemap from USGS, Esri, NOAA, and other contributors

The geologic background of Thailand indicates a long and complex evolution. During the Cenozoic Era, tectonic deformation of Thailand with faulting and crustal uplift and subsidence has affected by the crash of the Indian and Eurasian continental plates (Morley, et al. 2011). Quaternary basalt effusive rocks in north and northeast of Thailand and the emplacement of thin intrusive rocks, including geyserite at the west coast, indicates additional evidence for ongoing crustal deformation. Quaternary fluvial, coastal processes, and Holocene eustatic sea level fluctuations have been caused by tectonism (Morley, et al. 2011). The country can be divided into seven main areas of Cenozoic deformation. The four northern areas comprise the Western Highlands, the Central Basin, North Central Region, and the Khorat Plateau. The three southern areas include Peninsular Thailand, the Gulf of Thailand, and the Andaman Sea (Morley, et al. 2011). Most of the Central Basin is covered by Quaternary sediments and forms a broad flat plain that narrows northward. Quaternary sediments cover several basins formed in response to dextral shear on the Mae Ping and Three Pagodas Fault Zone systems during the Tertiary. The northern, western, and peninsular regions of Thailand are dominated by Paleozoic rocks with small, deformed outliers of Mesozoic strata, and infrequent small Tertiary basins. Most of Thailand is covered with tropical rain forest and the surface rocks are intensely weathered. The Khorat Plateau in the northeast is normally more arid than other regions and parts are covered with bush.

The central part of the country is a broad alluviated plain. From the Gulf of Thailand northward about 400 km the plain rises from sea level to 100 m elevation (Shawe 1984). The plains are 450 km long, up to 125 km wide and range in elevation from sea level to +50 m. The plains are a remarkable expression of the extensive, young post–rift Chao Phraya Basin, formed during the Late Miocene or Early Pliocene. It lies unconformably on the Late Oligocene–Miocene rift basins and interfering pre–Cenozoic rocks. The Chao Phraya Basin is the most fertile agricultural region in Thailand (Morley, et al. 2011). The North Central Area is characterized by over 40 intermontane rift basins forming isolated plains at elevations between 200 m and 500 m. The plains are edged by high hills with elevations generally up to 1,500 m, composed predominantly of Palaeozoic–Early Mesozoic rocks (Morley, et al. 2011). Extensive deposits of Quaternary non–marine sediments form the Central Plain area and are overlain with thick marine Holocene clay in the Lower Central Plain (Dheeradilok 1995).

The central plain is mainly a cultivated region where rice is the principal crop (Shawe 1984). The Lower Central Plain has been formed by fluvial and deltaic deposition by the Chao Phraya, Mae Klong, Tha chin, and Bang Pakong rivers, as well as coastal progradation deposition with sediment transported into the plain by longshore current. Landscape topographies include tidal flats and beaches (Dheeradilok 1995). The coastal Lower Central Plain developed during the Holocene marine transgression and subsequent coastal progradation at about 11,000 to 3,000 BP, as fluvial and coastal processes fluctuated to the rising and consequently stable sea level. The Holocene marine Bangkok Clay Formation which covers most of the Lower Central Plain accumulated during this period. The 650-m thick Plio–Pleistocene, fluvial, and deltaic sedimentary deposits that underlie the Holocene deposits are a product of Cenozoic tectonic subsidence within the basin as well as erosion and depositional processes modifying to tectonic uplift of the nearby Western Highlands (Dheeradilok 1995).

The northeastern Thailand has an area about 400 km by 400 km, mostly 100–500 m in elevation. The Khorat Plateau is a saucer-shaped low platform with a geologically stable region made up dominantly of marine sedimentary rocks of Mesozoic age. Tertiary and Quaternary volcanic rocks arise along the western and southern borders of the Khorat Plateau (Shawe 1984). The interior region is undulating and dotted by several low hills and small shallow lakes (Pendleton

1962). The Khorat plateau is rimmed by an escarpment of steeply dipping sediments which form ridge on its western and southern margins, mostly 600 –1,000 m above MSL. The Plateau extends northward and eastward across the Mekong River into Laos. The Phu Phan Range divides the plateau into two basins, namely the Khorat in the south and the Sakhon Nakhon in the north. The predominant landscapes are low hills and edges with broad peaks and moderate straight slopes divided by extensive valleys (Wannakomol 2005).

Northwestern Thailand has an area about 600 km from north to south and 300 km from east to west and. The region contains a series of north–trending mountain ranges 500–2,000 m high, and intermontane basins 200–500 m high. It consists of strongly folded and faulted sedimentary rocks, mostly marine and of Paleozoic and Mesozoic age. The sedimentary rocks locally are disrupted by batholithic granites of Carboniferous–Permian, Triassic, Jurassic, and Cretaceous–Tertiary ages. These sedimentary rocks are interlayered with mafic igneous rocks of Carboniferous age, or intruded by Tertiary and Quaternary volcanic rocks (Shawe 1984).

The Southern Thailand Peninsula can be divided into two regions, namely the west coast and east coast. Quaternary depositional processes within each region have been categorized based on paleoenvironments into fluvial, coastal, laterite, volcanic, and lacustrine deposits. The stratigraphic sequences have been broadly grouped into Pleistocene and Holocene formations (Dheeradilok 1995). The Holocene–Pleistocene boundary can be visibly distinguished at the coast by a sudden change in uniformity from a soft marine clay to a rigid fluvial sand and clay. In highland areas, a laterite formation can be utilized as an essential indicator of the Pleistocene–Holocene boundary. The laterites of Pleistocene age can be identified by horizontal embedded tektites (Dheeradilok 1995).

The coastal processes on the east and west coasts are different. The west coast is characterized by numerous islands, drowned valleys, steep cliffs, shortened headlands, and small embayments. Embayments are backed by short and narrow beaches, distinguishing crescent shape beach ridges, and steep narrow floodplains with shallow deposits of Quaternary sediments shaped by the short and steep–gradient rivers that flow into the Andaman Sea. Headlands between the bays have steep cliffs and truncated rock spurs due to exposure to wave action along a high energy coast. Coastal wave action is dominated during the southwest monsoon from April to September. The rivers are short but have a steep–gradient, which creates shallow deposits of Quaternary sediments. In contrast, the east coast is a broad coastal plain with long beach ridges, sand spits, and lagoons. This coast has formed as a result of the postglacial marine transgression and subsequent coastal progradation. Sand developed from erosional processes in the western upland area and transported to the coastal area by rivers. The east coast longshore current transports sediment causes by coastal progradation (Dheeradilok 1995). Tidal flats with large lagoons and sand spits are also common along the east coast. These geomorphic features are a result of Holocene coastal progradation. The rivers-depositing sediment originated from erosion in the western upland (Dheeradilok 1995).

The Quaternary is a period characterized by climatic change, sea–level change, changing landforms, migration of lives on the earth surface, and human evolution. This period is subdivided into two epochs, namely the Pleistocene (1.8 million years–10,000 years BP) and the Holocene (10,000 years BP–present). Quaternary geologic sequences of Thailand cover one–third of the total area. They are mainly semiconsolidated and unconsolidated sediments, including some rapid crystalline and lithified volcanic rocks such as basalt. The classification of Quaternary sediments in Thailand is based on geomorphology, lithology, depositional environments, and fossils.

Normally, Pleistocene deposits are related to neo–tectonics, changes in alluvial and fluvial systems, in-place weathering of the bed rocks, and evidences of sea–level change in restrictive areas. On the other hand, Holocene deposits are related primarily to climatic changes and marine sediments resulting from the great fluctuation of sea level. The present coastal area of Thailand was formed by inundation of Holocene sea level. While in the upland area, flood plains, levees, and young alluvial fans were developed. Igneous rocks are widespread in Thailand. Among them, granites are the most common, whereas intrusive rocks of intermediate, mafic, ultramafic composition, and volcanic rocks are subordinate. Volcanic rock groups are widely distributed in most parts of Thailand, for instance Chang Mai and Chiang Rai provinces in the north, Tak province in the west, and Ko Chang island in the east. In addition, Metamorphic rocks are arcuately elongated in a north–south direction (Figures 2.21 and 2.22) (Department of Mineral Resources 2016).

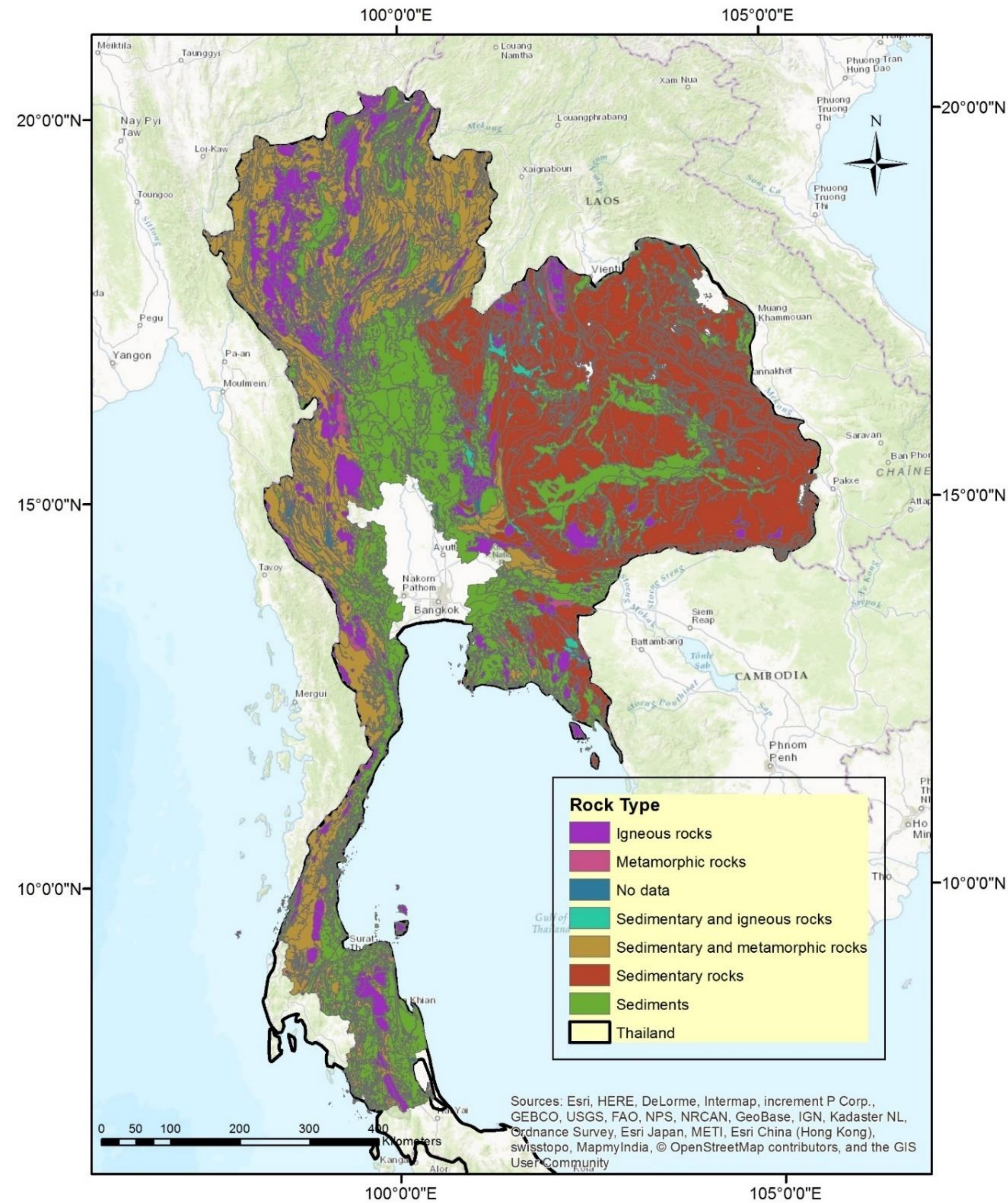


Figure 2.21: Major rock type of Thailand, data from Department of Mineral Resources, map by Areerut Patnukao, map sources from USGS, Esri, NOAA, and other contributors

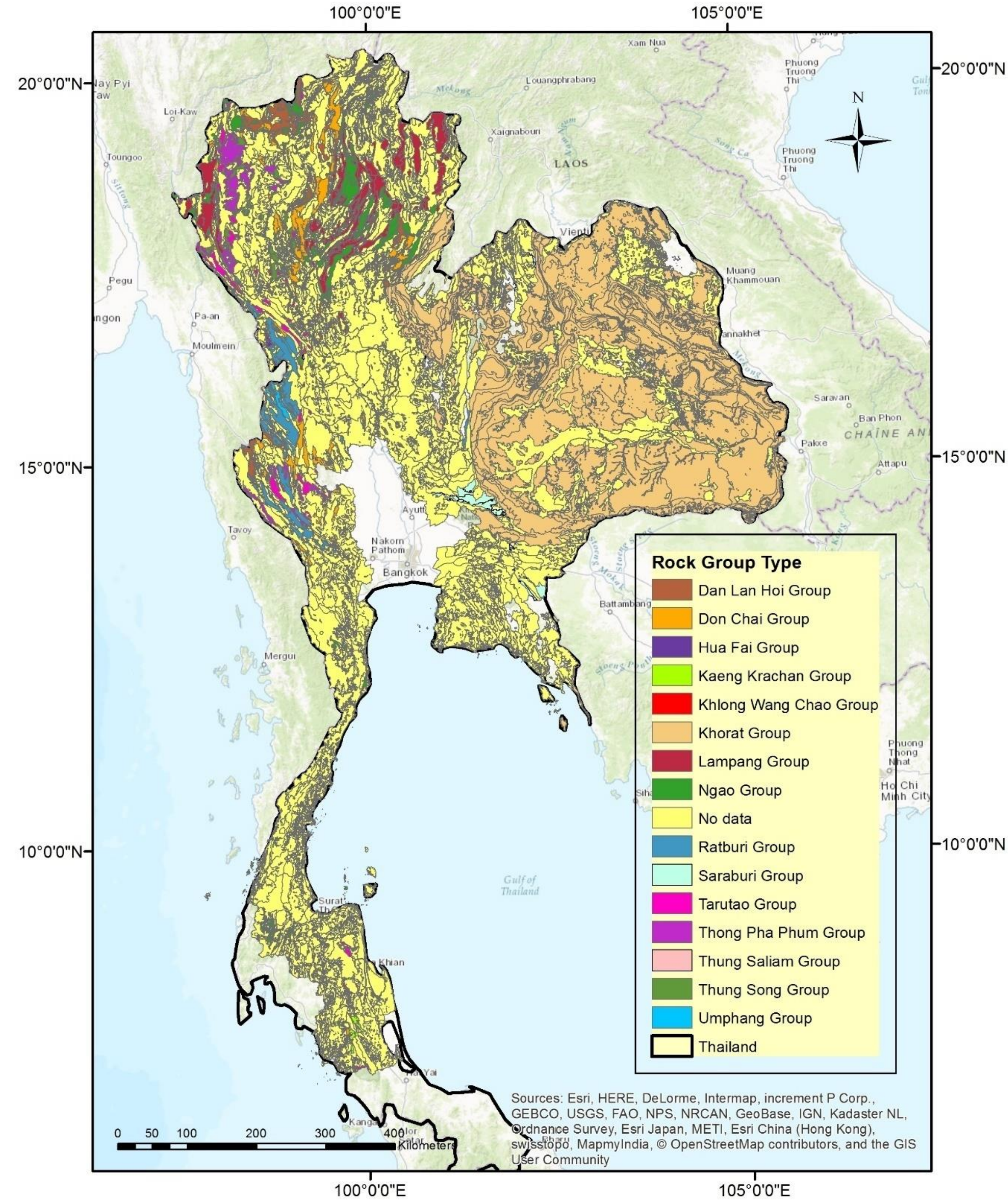


Figure 2.22: Rock group type of Thailand, data from Department of Mineral Resources, map by Areerut Patnukao, map sources from USGS, Esri, NOAA, and other contributors

2.3.3 Hydrology

Due to geographical characteristics and hydrological aspects, river basins in Thailand can be separated into 25 river basins and 254 sub–basins (Figure 2.23). The rainy season, which occurs from May to October is controlled by the southwest monsoons and tropical storms from the Bay of Bengal. The dry season occurs from November to April, under influence of the northeast monsoon from China and tropical storms from the South China Sea (Bank 2011). Rainfall varies over time and place. The average of annual rainfall countrywide is about 1,700 mm, ranging from 1,200 mm in the north and central plain to above 2,000 mm in the eastern part and southern parts of the country. The southern region has the highest rainfall and August and September are the wettest months. The total volume of annual rainfall from all river basins is about 800,000 million m^3; 75 percent of this volume (or 600,000 million m^3) is lost through evaporation, evapotranspiration, and infiltration, while the remaining 25 percent (or 200,000 million m^3) is the runoff that flows in streams, rivers, and reservoirs. Runoff is the volume of rainwater that flows over the land and is measured in m^3/year/person. It varies due to geographic landscape and land–use. Therefore, the available water runoff is about 3,300 m^3/year/person (Bureau of Resources Development and Hydrology 2009; Sethaputra, et al. 2001) (Table 2.1 and 2.2).

Table 2.1: Thailand's surface water resources

Region	**Catchment area (km^2)**	**Average annual rainfall (mm/year)**	**Amount of rainfall (million m^3)**	**Amount of runoff (million m^3)**
Northern	169,640	1,280	217,140	65,140
Central Plain	30,130	1,270	38,270	7,650
Northeast	168,840	1,460	246,500	36,680
Eastern	34,280	2,140	73,360	22,000
Western	39,840	1,520	60,560	18,170
Southern	70,140	2,340	164,130	49,240
Total	**512,870**	**–**	**799,960**	**198,880**

Table 2.2: 25 river basins of Thailand (Bank 2011; Bureau of Resources Development and Hydrology 2009)

Basin No.	**Name of river basin**	**Number of Sub–basins**	**Catchment area (km^2)**	**Average runoff (10^6 m^3)**	**Storage capacity (10^6 m^3)**	**Irrigation area (km^2)**
1	Salawin	17	19,105.94	8,571	24	302.32
2	Mekong	37	57,188.60	19,362	1,551	2,707.73
3	Kok	4	7,299.83	5,279	30	833.23
4	Chi	20	49,129.87	8,752	4,246	2,981.08
5	Mun	31	71,071.57	26,655	4,255	2,911.66
6	Ping	20	34,499.39	7,965	14,107	3,108.68
7	Wang	7	10,793.57	1,104	197	755.76
8	Yom	11	23,948.15	3,117	98	1,590.73
9	Nan	16	34,908.11	9,158	9,619	2,849.02
10	Chao Phraya	2	20,266.49	22,015	33	9,170.20
11	Sakae Krang	4	5,055.88	1,297	162	698.26
12	Pasak	8	15,623.36	2,820	124	1,057.79
13	Tha Chin		13,491.63	22,300	416	3,816.41
14	Mae Klong	11	30,180.71	7,973	26,690	5,440.00
15	Prachin Buri	4	9,672.10	5,192	57	1,174.18
16	Bang Prakong	4	10,700.71	3,713	74	2,165.22
17	Tonle Sap	3	4,085.93	6,266	96	197.95
18	Peninsular East Coast	6	13,093.05	11,115	565	683.20
19	Phetchaburi	3	6,260.17	1,400	750	900.30
20	Peninsular West Coast	5	7,132.81	1,420	537	523.22
21	Southeast Coast	13	26,067.89	23,270	5	2,848.77
22	Tapi	8	13,561.81	12,513	5,865	393.55
23	Songkhla Lake	3	8,481.28	4,896	28	1,448.88
24	Pattani	2	3,654.87	2,738	1,420	540.60
25	Southwest Coast	13	18,775.60	25,540	20	542.84
	TOTAL		**514,049.33**	**244,431**	**70,769**	49,641.58

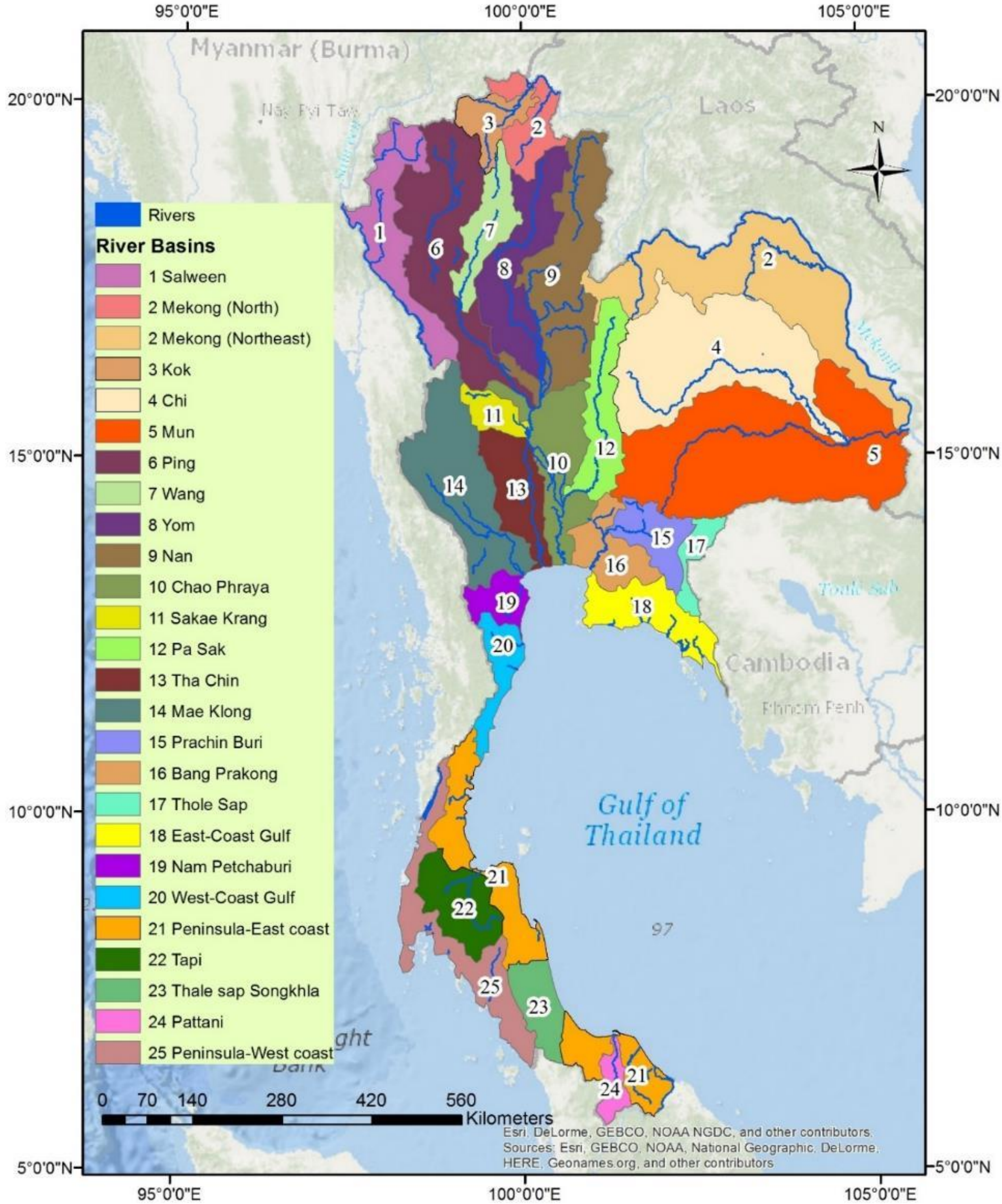


Figure 2.23: Map of 25 River Basins in Thailand, Data from Bureau of Resources Development and Hydrology (2009), digitized and mapped by Areerut Patnukao, basemap from Esri and other contributors

The 25 basins can be grouped into six geographic regions: North, Central Plain, Northeast, East, West, and South. The North of Thailand is above 200 m high. The mountains serve as the source of four major rivers (Ping, Wang, Yom, and Nan) which unite to become the Chao Phraya River, the major river of the Central Plain. The North–Central basin also has high storage capacity (35 %), with the largest area under irrigation (Bank 2011). The North region includes Salween, Ping, Wang, Yom, Nan, Kok, and Mekong (North).

The Central Plain is the most important economic area of Thailand. It is also the most agriculturally productive area, but it is short of large water sources. The water demand exceeds locally existing supply. The Chao Phraya River system is the main river system of Thailand. This river system depends heavily on water from river basins upstream in the north area. The Chao Phraya River starts at the convergence of the Ping, Wang, Yom, and Nan Rivers in Nakhon Sawan province. Afterward, it flows from the central plains through Bangkok to the Gulf of Thailand (Bank 2011; Pink 2016). The basins in Central Plain include Sakae Krang, Tha Chin, Chao Phraya, and Pa Sak.

The Northeast region covers one–third of Thailand and it is part of the Mekong River basin. One–third of the country's rivers flow into the Mekong, which is the only river system in Thailand that flows into the South China Sea. The basins in this region are Chi, Mun, and Mekong (Northeast). The Northeast is a dry plateau with 100–200 m high. The region suffers from floods during the tropical storm period and droughts during the dry season. Although rainfall in this region is similar to the national average, a high evaporation rate and a porous saline soil limit agricultural development and productivity (Jaiborisudhi 2010). Because it is geographically unsuitable for large–scale water storage, this region inadequately server the local demand. The region depends on medium and small–scale water storage and on inter–basin transfer (Bank 2011).

The East region has several short rivers, which are suitable only for medium–sized water storage projects. Consequently, this region has lower storage capacity and water shortage (Bank 2011). The basins in this region are the East–Coast Gulf, Thole Sap, Prachinburi, and Bang Prakong.

The West basins have the largest storage capacity, with the smallest total irrigation area. Mostly the reservoirs in the West were created for hydropower generation (Bank 2011). The basins in this region include West–Coast Gulf, Phetchaburi, and Mae Klong.

The Southern area is wetter than the rest of the country (Tangtham 1996). It has various short rivers and high annual rainfall. There are several large water reservoirs. Water shortage is limited to a few places and is less severe than elsewhere (Bank 2011). The basins in this region are Thale sap Songkhla, Tapi, Peninsula–East coast, Peninsula–West coast, and Pattani.

2.3.4 Soil

Soils were considered as independent natural bodies. The morphology of each soil indicates the combination of factors accountable for its development. These factors are a unique mixture of climate, earthy parent material, living materials, relief, and age of landforms (Soil Survey Staff 1999). Soil covers almost of the earth's surface, except on bare rock, permanent frost, deep water, or bare ice of glaciers (Soil Survey Staff 1999). The environmental conditions in Southeast Asia, including climate, vegetation, physiography, geology, and lithology, significantly vary which consequently influent soil type.

Soil Subgroups in Thailand

There are 10 soil groups found in Thailand, namely Acrisols, Ferralsols, Fluvisols, Gleysols, Histosols, Lithosols, Luvisols, Nitosols, Regosols, and Vertisols (Figure 2.24) (FAO-UNESCO 2007). These soil groups also can be divided into soil subgroups shown in Figure 2.25.

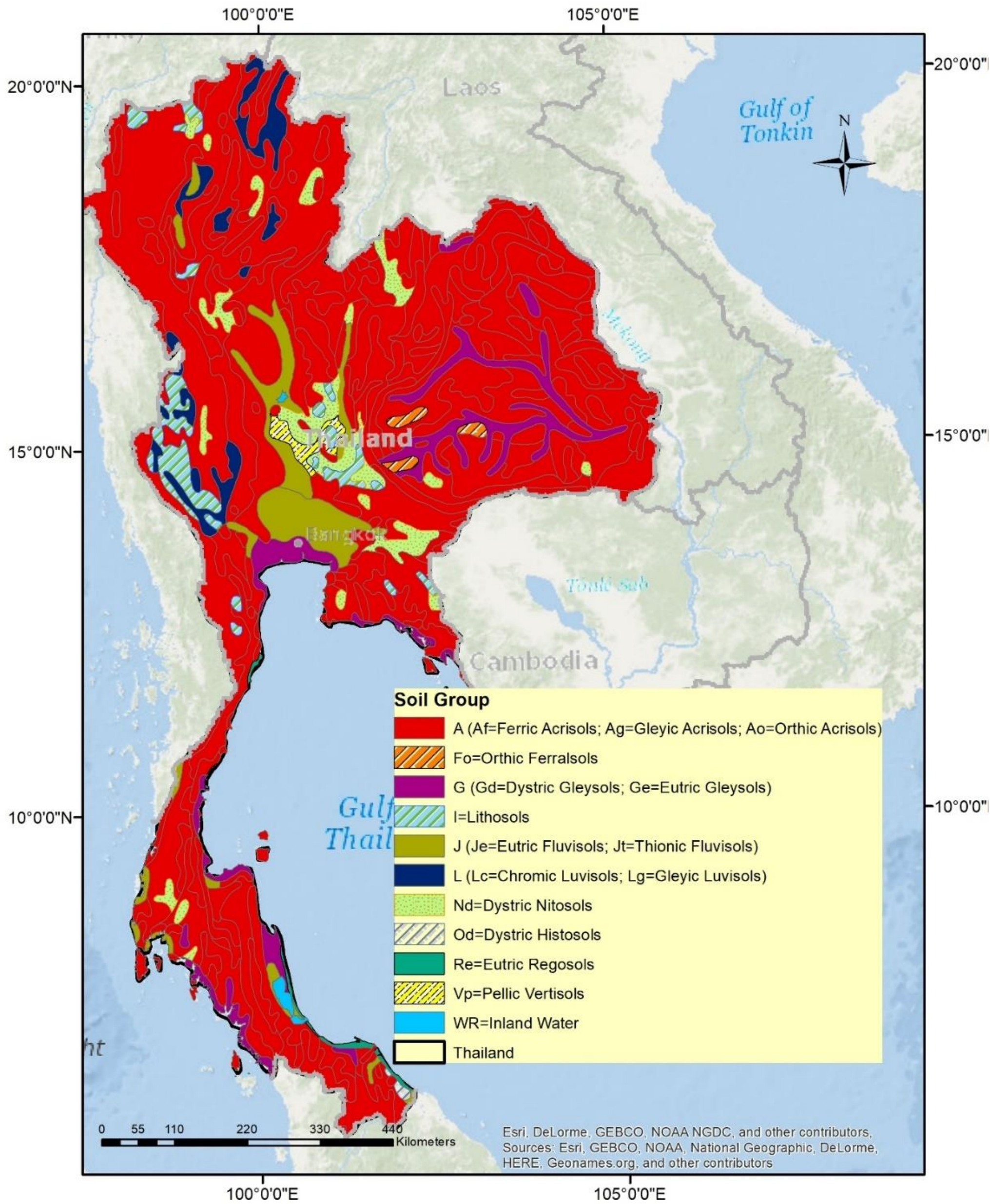


Figure 2.24: 10 soil groups found in Thailand, vector dataset of soils retrieved from FAO–UNESCO Soil Map of The World at 1:5,000,000 scale (FAO-UNESCO 2007), map by Areerut Patnukao, basemap from Esri, GEBCO, NOAA, National Geographic, and other contributors

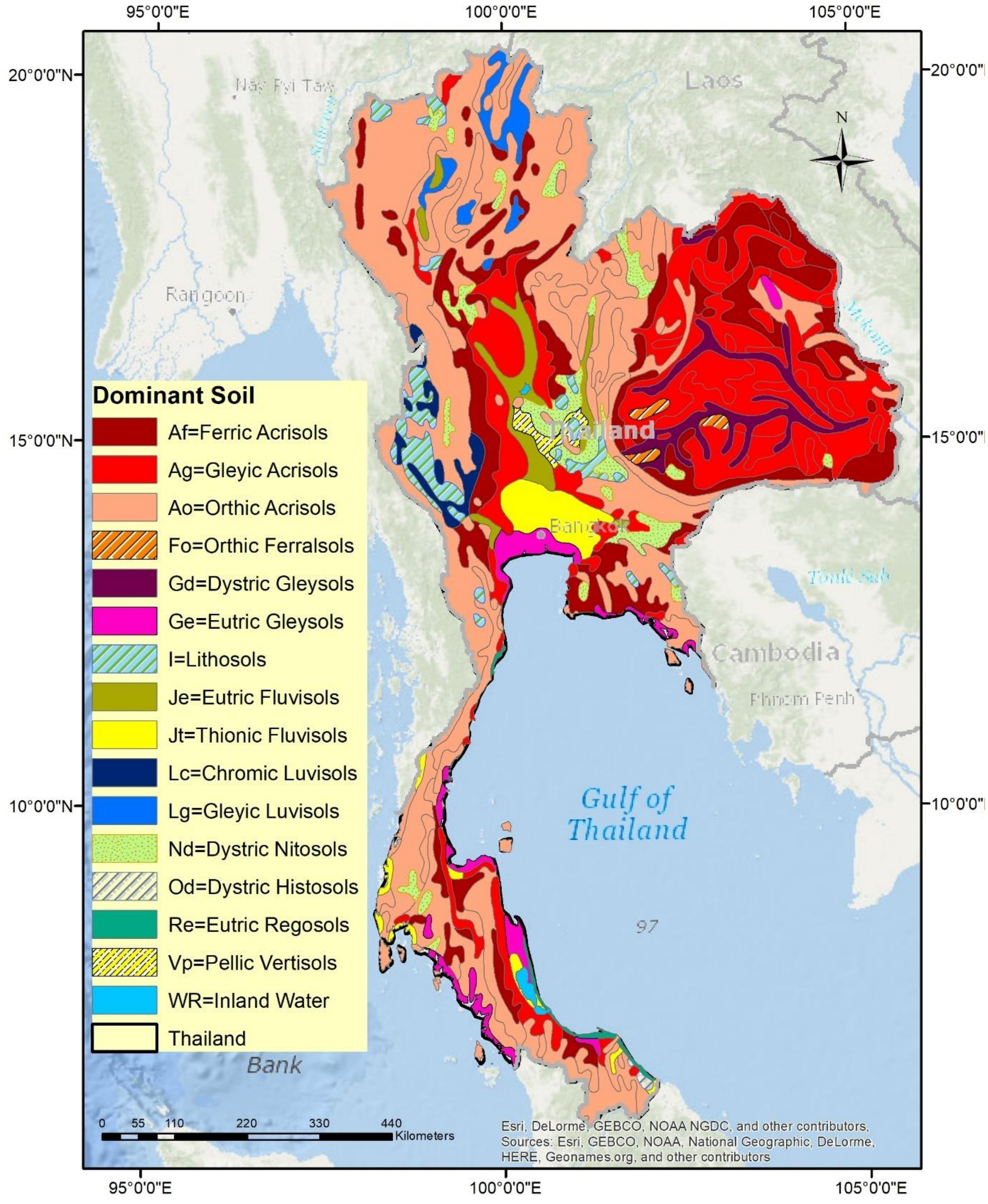


Figure 2.25: soil subgroups found in Thailand, vector dataset of soils retrieved from FAO–UNESCO Soil Map of The World at 1:5,000,000 scale (FAO-UNESCO 2007), map by Areerut Patnukao, basemap from Esri, GEBCO, NOAA, National Geographic, and other contributors

Acrisols (A)

Acrisols are characterized by a subsurface accumulation of low activity clays in an argic subsurface horizon, a distinct clay increases with depth, and a low base saturation level in the 50–100 depth (Driessen, et al. 2001; Group 2014; Spaargaren 2001). These soils have been named red–yellow podzolic soils (FAO/UNESCO 1974). Ferric Acrisols (Af) are found in the more humid parts of Thailand. The macrorelief is undulating to rolling. The natural vegetation is tropical lowland evergreen rain forest. Large tracts of land have been brought under shifting cultivation of upland rice and cassava, with poor results, leading to the development of anthropic savanna dominated by cogon grass. Rubber, under careful management, is probably the best tree crop for these soils (FAO/UNESCO 1979). Gleyic Acrisols (Ag) occur mainly in northeastern Thailand. Their macrorelief ranges from nearly level to rolling. The natural vegetation is tropical dry deciduous forest. In low–lying and level areas one crop of rice is grown annually during the rainy season, and crop failures may occur in years with low or poorly distributed rainfall. Orthic Acrisols (Ao) are the most common soil group of Thailand. They are developed from sedimentary rocks, old alluvial deposits, and acid and intermediate igneous and metamorphic rocks. The majority are found on well–drained, gently undulating to rolling uplands, hilly land and mountain slopes of low and intermediate elevations, and on well–drained old alluvial terraces. A lithic phase is common on steeply dissected and mountainous slopes. The natural vegetation ranges from tropical evergreen rain forest in southern Thailand to tropical deciduous and montane laurel forest in northern Thailand. Shifting cultivation has been practiced over wide areas since ancient times, often resulting in the development of a fire climax anthropic savanna. During the last century, rubber and oil palm are the most important permanent crops (FAO/UNESCO 1979).

Ferralsols (F)

Ferralsols represent the deeply weathered, red or yellow soils of the humid tropics. These soils have disperse horizon boundaries, a clay accumulation dominated by low activity clays (mainly kaolinite), and a high content of sesquioxides (Driessen, et al. 2001). Physically, Ferralsols have a stable, weakly expressed soil structure, a low silt/clay ratio, and a very low content of weatherable minerals. They are less prone to erosion due to their depth, high permeability, and stable microstructure. Water holding capacity in Ferralsols is usually low. Soil porosity is high, so roots penetrate deeply in Ferralsols (Spaargaren 2001). Orthic Ferralsols (Fo) are developed on old alluvial terrace remnants in northeastern Thailand. Their macrorelief is generally undulating to rolling. The natural vegetation is tropical dry deciduous forest. Most of these soils have been used to shifting cultivation and are often uninhabited to anthropic savanna. These soils are being abandoned to low–intensity grazing due to more dry season and lack of irrigation water (FAO/UNESCO 1979).

Fluvisols (J)

Fluvisols are young soils in fluvial, lacustrine, or marine deposits and show slight horizon differentiation (Driessen, et al. 2001; Group 2014). They occur on materials deposited in aqueous sedimentary environments. There are three situations in which fresh material is continually added by sedimentation from water: the inland fluvial and lacustrine fresh–water environments, the marine environment, and the coastal saltings or brackish marsh environment (Spaargaren 2001). Fluvisols have a sulfuric horizon or sulfidic material, or both, at less than 125 cm from the surface (FAO/UNESCO 1979). Eutric Fluvisols (Je) occur in the alluvial plains of the Chao Phraya and are dominant in the coastal plains of southern Thailand. They are developed on recent alluvium derived mostly from intermediate to basic parent rocks. Their macrorelief is generally flat, although levees often have an undulating microrelief. Soils subject to deep flooding remain under mixed swamp forest. Along coasts, soils which are occasionally inundated by sea water are mostly under mangrove, which is intensively used for charcoal making. These soils are developed on new alluvium derived mostly from intermediate to basic parent rocks. With available irrigation water, rice is the dominant crop and can be grown twice a year. In some areas, these soils are provided flood protection. On well–drained levee soils, a variety of fruit and vegetable crops are grown together with industrial crops such as coconuts. Thionic Fluvisols (Jt) occur mainly in the Chao Phraya delta and to a lesser extent in tidal swamps along the coasts of Thailand. They are developed on brackish water alluvium holding large amounts of sulphides, mainly pyrites. The natural vegetation contains mainly Avicennia and Rhizophora mangroves. The soils are not suitable for growing rice (FAO/UNESCO 1979).

Gleysols (G)

Gleysols consist of soils saturated with groundwater for long enough periods to develop a characteristic gleyic color pattern. This pattern is principally made up of reddish, brownish, or yellowish colors at aggregate surfaces and/or in the upper soil layers, as well as in combination with greyish/bluish colors inside the aggregates and/or deeper in the soil (Driessen, et al. 2001; Group 2014). Most Gleysols have natural swamp vegetation or are used for grazing. In tropical and subtropical areas, rice is widely grown in Gleysols. They can be used for arable cropping, dairy farming, or horticulture (Spaargaren 2001). Eutric Gleysols (Ge) occur mainly in Chao Phraya delta. They occur in elevated coastal flats and low river terraces. They are developed on subrecent alluvium obtained from more basic parent material. Their original mixed-swamp forest has been mostly cleared and are intensively used for irrigated rice, or rice in rotation with vegetables, pulses, tobacco, and sugar cane. Saline–phase soils occurring on the coastal flats of

Thailand are used for salt pans. Dystric Gleysols (Gd) occur mainly in Mun and Chi river basins in northeast Thailand. They are developed on riverine alluvium and occupy low river terraces. Their macrorelief is largely flat. They are waterlogged and flooded during the rainy season, but dry out to some depth during the dry season. The natural vegetation, mixed swamp forest, has been mostly cleared for rice growing. Most areas produce one crop of rain-fed rice a year, or two crops yearly where sufficient irrigation is available (FAO/UNESCO 1979).

Histosols (O)

Histosols are unlike all other soils in that they are formed in organic soil material with physical, chemical, and mechanical properties that differ significantly from those of mineral soil materials. They develop in conditions where organic material is produced by an adapted vegetation. They also occur where biochemical decomposition of plant debris is retarded by low temperatures, persistent waterlogging, extreme acidity, oligotrophy, and/or the presence of high levels of electrolytes or organic toxins. Organic soil material is defined as soil material that contains more than 20 percent organic matter. Organic materials accumulated in different environments are generally of different composition and have different chemical, physical, and mechanical properties. The combination of specific environmental conditions, the actual composition of the organic soil material, and the degree of decomposition lead to different types of Histosols (Driessen, et al. 2001; Spaargaren 2001). Histosols are formed in organic material accumulating as groundwater peat, rainwater peat or mangroves or without water saturation in cool mountain areas. They vary from soils developed in moss peat in arctic, subarctic, and boreal regions, via moss peat, reeds/sedge peat and forest peat in temperate regions to mangrove peat and swamp forest peat in the humid tropics (Group 2014). Histosols occur at all altitudes but mostly occurs in lowlands. Common international names are peat soils, muck soils, bog soils, and organic soils (Driessen, et al. 2001). Dystric Histosols (Od) are extensive in low coastal areas of southernmost of Thailand. They have developed over subrecent coastal swamps with a flat to slightly depressed concave environment where conditions are favorable for the accumulation of organic matter and plant debris. Most Dystric Histosols occur in rain–dependent, nutrient–poor ombrogenous peat bogs which are domed. Most remain under tropical flood-swamp forest. Land use is mainly restricted to gathering of useful natural products, which are abundant in certain areas. Mostly on shallow peat, oil palm, rubber, coconuts, pineapples, root crops, ramie fiber, and vegetable crops are grown (FAO/UNESCO 1979).

Lithosols (I)

Lithosols are very thin soils developed on hard rock (Latham 1982). They are shallow mountain soils limited in depth by constant coherent and hard rock within 10 cm of the surface (FAO/UNESCO 1974). Lithosols are shallow and poor soils with little agricultural potential. They occur mainly in the western part of Thailand. Lithosols are found on a wide variety of parent rocks, but they are most extensive on limestone. Their macrorelief is generally steeply dissected to mountainous area. The landscape is a very rocky character. Vegetation cover is patchy with nearly bare rock outcrops. They are highly vulnerable to erosion. Rock outcrops and steep slopes commonly make them unsuitable for cultivation or irrigation. Land use is restricted to shifting cultivation on relatively deeper soils (FAO/UNESCO 1979).

Luvisols (L)

Luvisols have an argillic horizon which has a base saturation of 50 percent or more at least in the lower part of the B horizon within 125 cm of the surface (FAO/UNESCO 1979). They have a higher clay content in the subsoil than in the topsoil due to pedogenetic processes (especially clay migration). Luvisols are defined by textural differentiation, the cation exchange capacity of the clay, and the aluminium saturation. The genesis of an argic horizon in Luvisols is attributed to eluviation and illuviation of clay occurring in the surface and subsurface horizons respectively. The presence of an argic horizon is a mark of a stable land surface. If an argic horizon is formed mostly by illuviation, it also shows a seasonally dry period during which clay can flocculate on ped surfaces in the form of clay coatings or argillans (Spaargaren 2001). Chromic Luvisols (Lc) occur in small areas of western Thailand. They are developed from the weathering products of olivine basalt, intermediate volcanic tuff and lahar, limestone, marl, and claystone. Their macrorelief is predominantly steeply divided. Steep, stony, and shallow Chromic Luvisols remain under tropical evergreen rain forest or tropical deciduous forest. On gentler slopes, many of these soils have been used for shifting cultivation and are often abandoned to scrub and anthropic savanna following excessive erosion. In Thailand, maize, sorghum, cotton, vegetables, and various fruit crops are grown. Gleyic Luvisols (Lg) are not extensive, occurring mainly in some parts of northern Thailand. They are developed on old terrace alluvium in intermontane basins. Their macrorelief is nearly level to rolling. The dry deciduous forest has been largely cleared for rainfed rice cultivation, with steeper slopes being terraced. Tobacco is mostly planted on poorly drained soils. Where supplementary irrigation is possible, rice is followed by a summer vegetable or pulse crop (FAO/UNESCO 1979).

Nitosols (N)

Nitosols have an argillic B horizon with deeply stretched clay distribution where the percentage of clay does not show a relative decrease from its maximum of more than 20 percent within 150 cm of the surface. (FAO/UNESCO 1979; Spaargaren 2001). Nitisols are deep, well–drained soils with a typical nutty or polyhedral blocky structure and shiny ped faces. They are dusky red or dark red and have a clayey or fine clayey texture (Spaargaren 2001). Dystric Nitosols

(Nd) occur in some small parts of Thailand. They are developed on various highly weathered rocks and sediments and have a nearly level to hilly macrorelief. The natural vegetation is mainly tropical evergreen rain forest, but extensive areas have been cleared for both shifting and permanent agriculture. Main plantation crops are rubber, oil palm, coffee, cocoa, fruit, abaca, and coconut (FAO/UNESCO 1979).

Regosols (R)

Regosols are very weakly developed mineral soils in unconsolidated materials. They are extensive in eroding lands and accumulation zones, mainly in arid and semiarid areas and in mountainous regions (Group 2014). Eutric Regosols (Re) occur on recent sandy coastal sediments and dunes along the shores of Thailand, especially in the east–coast gulf. Eutric Regosols on recent beach and dune deposits have a nearly level to rolling macrorelief, and those on volcano slopes occupy hilly to steeply dissected terrain. Vegetation on these coastal sans is sparse and scrub–like. On the mainland, Eutric Regosols are used for coconut and casuarina plantations and recreation. The sandy Eutric Regosols of beaches and dunes are coarse textured, deep, and excessively drained. Soil is slightly acid with low organic matter content and moderate base status. The moisture-and nutrient-retention capacities are commonly low. Their agricultural potential is also low. The best crops for permanent agriculture are coconut and casuarina or pine plantations (FAO/UNESCO 1979).

Vertisols (V)

Vertisols are mixed heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years (Driessen, et al. 2001; FAO/UNESCO 1979; Group 2014). Vertisols are deep clayey soils (>30 % clay) dominated by clay minerals such as smectite that expand upon wetting and shrink upon drying. The upper part of the soil usually consists of strong, prism–like blocks (Spaargaren 2001). Pellic Vertisols (Vp) occur where a distinct monsoon climate exists, particularly in upper central plain of Thailand. They are developed from various parent materials including old clay terrace alluvium, old basic volcanic rocks, and limestone–clay sediments. Their macrorelief is nearly level to gently undulating and is occasionally cut by erosion gullies and crevices. A distinguishing gilgai microrelief is commonly found. Most Pellic Vertisols are used for cultivation. In areas with sufficient irrigation, rice can be grown twice yearly. In insufficient irrigation area, the soils are abandoned for low–intensity grazing (FAO/UNESCO 1979).

Soil Regions in Thailand

Based on climate, natural vegetation, main rocks, and distribution of the main soils, Southeast Asia has been classified into 19 soil regions and 10 soil subregions (Table 2.3) (FAO/UNESCO 1979).

Table 2.3: Southeast Asia has been divided into 19 soil regions and 10 soil subregions (FAO/UNESCO 1979)
* soil regions and subregions found in Thailand

No.	Soil regions	No.	Soil subregions
1*	Fluvisol–Gleysol association of the Chao Phraya, Mekong, and Red river deltas	1	Indochinese Peninsula
2*	Fluvisol–Gleysol association of Irian Jaya, the Circum-Sunda Archipelagoes and the Malay Peninsula	1a	Malay Peninsula
3	Gleysol–Vertisol association of lake Tonle	1b*	Western Highlands
4*	Lithosols	1c*	Central Highlands
5	Arenosol–Acrisol association off Borneo	1d*	Khorat Plateau
6	Rendzinas	1e	Eastern Highlands
7	Andosols of the Moluccas and Lesser Sunda islands	1f	Northern Highlands
8	Andosol–Luvisol association of Java	1g*	Chao Phraya Lowlands
9	Vertisol–Fluvisol association of Java and Madura	1h	Mekong Lowlands
10	Cambisols of Irian Jaya	2	Borneo

(table cont'd.)

Table 2.3: continued

No.	Soil regions	No.	Soil subregions
11	Cambisol–Andosol association of Sumatra	3	Philippines
12	Cambisol–Luvisol–Nitosol association of the Philippines	3a	Luzon
13*	Luvisols	3b	Mindoro
14	Podzols of Sumatra and Borneo	3c	Panay
15	Acrisols	3d	Negros, Cebu and Bohol
15a*	Acrisols of Continental Southeast Asia	3e	Samar and Leyte
15b*	Acrisols of the Malay Peninsula	3f	Mindanao
15c	Acrisols of Sumatra	3g	Palawan
15d	Acrisols of Borneo	4	Moluccas
15e	Acrisols of Sulawesi	4a	Ceram
15f	Acrisols of Irian Jaya	4b	Buru
15g*	Acrisol–Gleysol association of the Korat Plateau	4c	Misool
15h	Acrisol–Nitosol association of Java	4d	Obi
15i	Acrisol–Cambisol association of the Moluccas	4e	Sula Islands
15j	Acrisol–Nitosol association of the Philippines	4f	Halmahera
16*	Nitosols of Thailand and Laos	5	Sulawesi
17	Nitosol–Acrisol association of the Philippines	6	Lesser Sunda Islands
18	Ferralsols	6a	Wetar
19	Histosols	6b	Alor
		6c	Flores
		6d	Sumbawa
		6e	Lombok
		6f	Bali
		6g	Sumba
		6h	Timor
		6i	Tanimbar
		7	Java and Madura
		8	Sumatra
		9	Aru islands
		10	Irian Jaya

Based on FAO–UNESCO (1979) soil classification, soils in Thailand are classified into 7 soil regions and 4 soil subregions. These soil regions are 1) Fluvisol–Gleysol association of the Chao Phraya, Mekong, and Red river deltas, 2) Fluvisol–Gleysol association of the Irian Jaya, the Circum–Sunda archipelagoes, and the Malay Peninsula, 4) Lithosols, 13) Luvisols, 15a) Acrisols of continental Southeast Asia, 15b) Acrisols of the Malay Peninsula, 15g) Acrisol–Gleysol association of the Khorat plateau, and 16) Nitosols of Thailand and Laos. The soil subregions include 1b) Western Highland, 1c) Central Highlands, 1d) Khorat Plateau, and 1g) Chao Phraya Lowlands (Figure 2.26).

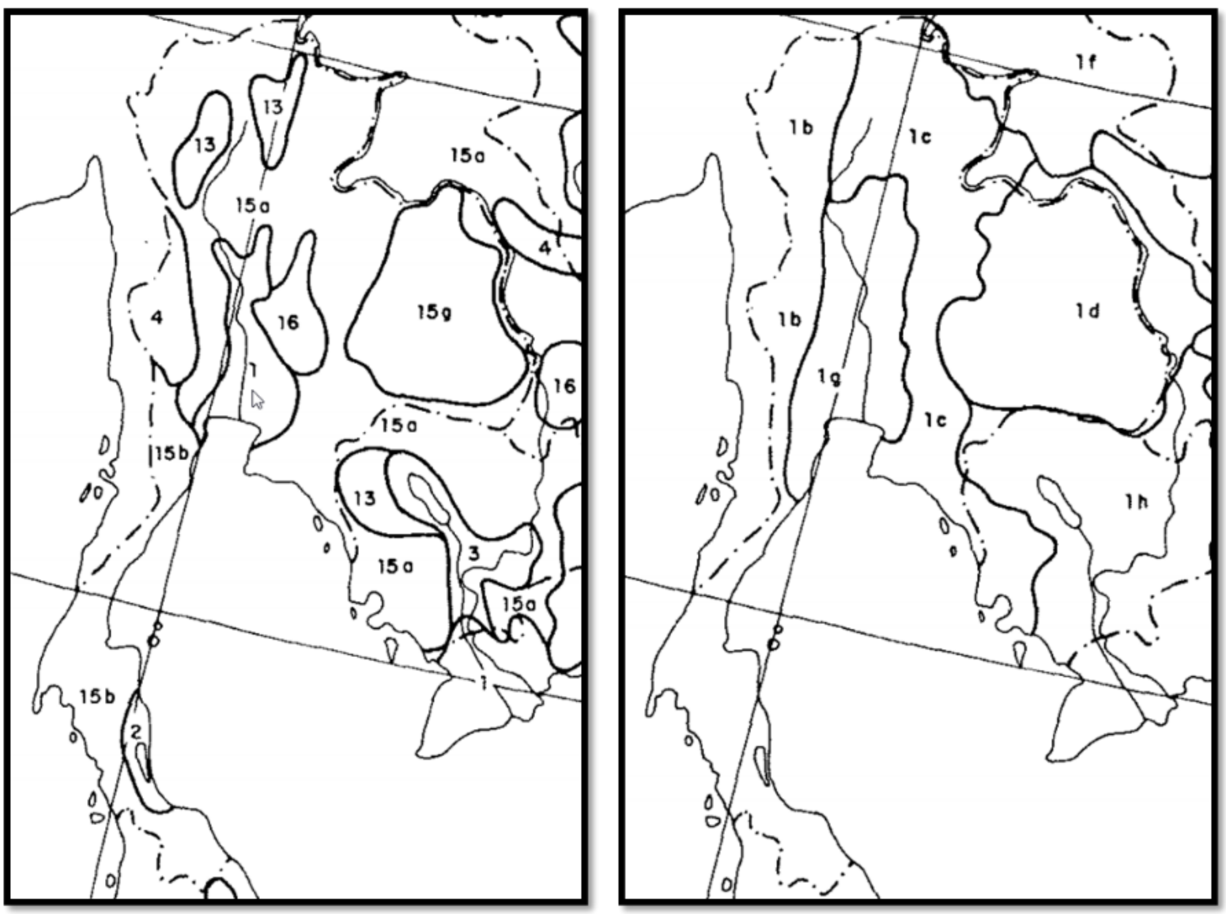


Figure 2.26: Based on FAO–UNESCO (1979) soil classification, Thailand covers 7 soil regions (Left) and 4 soil subregions (Right), figures obtained from parts of figures 6 (Right) and 7 (Left) in FAO–UNESCO (1979)

Region 1. Fluvisol–Gleysol association of the Chao Phraya, Mekong, and Red river deltas

The Chao Phraya, Mekong, and Red river deltas and alluvial plains developed the most massive area of Fluvisols in Southeast Asia. Fluvisols are formed from alluvial deposits and unconsolidated materials. Fine-textured Fluvisols are found throughout the region, while coarser textures are commonly limited to natural levees. The flood plain of Chao Phraya river is composed of Eutric Fluvisols, which developed from noncalcareous sediments. In the deltas and on coastal alluvial plains, Thionic Fluvisols have developed from brackish–water clays that have a high sulphide content. Thionic Fluvisols are most extensive in the Chao Phraya and Mekong deltas. Saline phase Eutric Fluvisols and saline Eutric Gleysols occur on the coastal fringes of the Chao Phraya and Mekong deltas. Gleysols are the major rice–growing soils of the region. An inclusion of Pellic Vertisols developed from lacustrine deposits borders the Chao Phraya flood plain in the east (FAO/UNESCO 1979).

Region 2. Fluvisol–Gleysol association of the Irian Jaya, the Circum-Sunda Archipelagoes and the Malay Peninsula

Fine–textured Thionic Fluvisols and Eutric Gleysols have developed from non–calcareous materials bordering Songkhla Lake in southern Thailand. Eutric Regosols are formed from beach and dune sediments along the littoral fringe, and inclusions of fine–to–medium–textured Gleyic Acrisols occur inland. The formations of narrow coastal plains occur along the east coast of Thailand are characteristic of emergent shorelines. The relief is mostly level, with a rolling microrelief occurring on natural levees and beach ridges of the littoral fringe. Elevation is at or near sea level, and much of the region is either permanently saturated or expose to annual flooding during the rainy season. The soils are developed from recent alluvial deposits and unconsolidated materials. The Fluvisols of the region are mainly immature and permanently saturated, but

Gleysols have matured to some degree due to better natural or artificial drainage (FAO/UNESCO 1979).

Region 4. Lithosols

Lithosols are limited in depth by continuous coherent hard rock within 10 cm of the surface. They are found in small numbers in areas of excessive relief. They may have a forest or savanna cover, or may be bare of vegetation, and may occur in any climatic region. However, in many areas these soils are widespread and have been united to form the Lithosols soil region. Mostly, the parent material consists of carbonate sediments, generally consolidated limestone or dolomite. The landscape is usually tropical karstic with highly weathered limestone ridges, isolated pinnacles, several caverns, and sinkholes. In the western highlands of Thailand, Lithosols occur on Carboniferous–Permian and Ordovician limestone which is massive and locally dolomitic (FAO/UNESCO 1979).

Region 13. Luvisols

Luvisols are commonly found in regions with a long distinct dry season, an annual rainfall of less than 1,500 mm, and a mean annual temperature over 20°C. This combination of climatic conditions is unusual in humid Southeast Asia. Subsequently, the occurrences of those soils are likely to be localized and are hardly continuous or extensive. Luvisols usually occur as inclusions or as secondary components of associations. Gleyic Luvisols occur mainly in the Ping and Yom basins of northern Thailand. They developed on Quaternary alluvium and colluvium from mixed basic and acid sources. These soils are fine textured and poorly drained. Their macrorelief is nearly flat to gently rolling. These soils are mainly used for rice agriculture (FAO/UNESCO 1979).

Region 15a. Acrisols of continental Southeast Asia

Found on the steeply divided terrain of the main mountain systems of Vietnam, Laos, Cambodia, and Thailand are fine–to–medium–textured and well to extremely drained lithic Orthic Acrisols. Acrisols are developed on residuals of consolidated clastic sediments and metamorphic and granite intrusive rocks. These soils are found mainly under natural broadleaf and pine forest. Steeper slopes remain under forest, while much of the rolling terrain is used for shifting cultivation, maize, and locally for rubber in eastern Thailand. Shifting farming is found on these soils, with widespread areas being abandoned to anthropic savanna. Flat and low–lying Gleyic Acrisols are used for rice growing.

Region 15b. Acrisols of the Malay Peninsula

Acrisols are dominant on steeply dissected terrain and the mountain ranges of southern Thailand Peninsular. Acrisols are characterized by fine–and medium–textured, well to excessively drained lithic Orthic Acrisols. In southern Thailand and Malaysia, rubber trees are widely planted on deeper, well–drained, medium–textured Orthic Acrisols on foothills and rolling old terraces. Coarse–and medium–textured, well to moderately well–drained Ferric Acrisols and poorly drained Gleyic Acrisols developed on old alluvium on lower terraces are poorly used for rubber plantation and are often abandoned to anthropic savanna. On flat and low–lying Gleyic Acrisols are suitable for growing rice.

Region 15g. Acrisol–Gleysol association of the Khorat plateau

The Khorat plateau in northeastern Thailand is mainly composed of the broad Quaternary terraces of the Mekong and its tributaries, the Mun and Chi rivers. Low, middle, and high terrace levels are recognized. Fine–textured, poorly drained Dystric Gleysols are developed on old alluvium of level, low terraces which are flooded during the rainy season. Medium– and coarse–

textured, poorly drained Gleyic Acrisols, and moderately well drained Ferric Acrisols are developed on old alluvium of middle terraces and have a predominantly undulating macrorelief. Fine–textured, well–drained Orthic Ferralsols occur on older high terrace remnants. The main inclusions are Orthic Acrisols on the steeply dissected slopes of scattered hills and bordering scarps. The Khorat plateau has been largely cleared of its original dipterocarp forest vegetation. Rice is grown during the rainy season on low lying level Dystric Gleysols and Gleyic Acrisols, and kenaf is widely grown on predominantly undulating terrain.

Region 16. Nitosols of Thailand and Laos

Nitosols are developed mainly from basalt, diorite and andesite, or biotite–rich granite and gneiss. Their macrorelief ranges from rolling to hilly. These soils occur in areas with an annual rainfall of 1,000–3,000 mm, temperature above 22°C, and a dry season of less than four months. In continental Southeast Asia, Nitosols seldom occur over widespread areas and are mostly limited to local basalt plateaus. Fine–textured, deep, well–drained Dystric Nitosols are developed on basaltic lava flows. In Thailand, the main inclusions are Lithosols, lithic Orthic Acrisols, Ferric Acrisols, and Pellic Vertisols. In the central highlands of Thailand Nitosols have been expansively cleared of natural dipterocarp forest and are planted in maize and sorghum (FAO/UNESCO 1979).

2.3.5 Climate

Thailand is influenced by the northeast monsoon during the dry season from October to February and by the southwest monsoon during rainy season from May to September (Figure 2.27). The highest temperatures of the year are recorded during the inter–monsoon season (March and April) (FAO/UNESCO 1979). The country is sheltered from the southwest monsoon during rainy season by the Tenasserim range and from the northeast monsoon during winter season by the mountainous relief of Vietnam. Overall, rainfall ranges from 1,000 to 1,500 mm, but exceeds

2,000 mm in the south and east. The northeast monsoon (beginning in mid to late November) brings cool dry air from the interior of the Asian continent to Thailand. This monsoon keeps the temperatures in Thailand fairly cool until its end in mid–February. The intermonsoon–months (March and April) bring thunder–showers throughout the country and raise the temperature higher in April (Pendleton 1962). The rainfall occurs over the country during the southwest monsoon, and is most frequent in September. The moist southerly current also brings rainfall as high as 400 mm to the coast east of Bangkok. The rainfall of this monsoon is determined by the interaction of the monsoon trench with westward–moving turbulence at high altitudes. The southwest monsoon may also be strengthened by residues of typhoons moving eastward from the China seas (FAO/UNESCO 1979). During the rainy season, the mountainous areas to the east and west of the Central Plain generate slight local variations in climate. Some parts of the western Central Plain are in rain shadows during the southwest monsoon, because rain is blocked by the Tenasserim range. In contrast, the eastern marginal plains of the Central Plain have increasing rain since this monsoon comes up against the Khorat Plateau (Pendleton 1962).

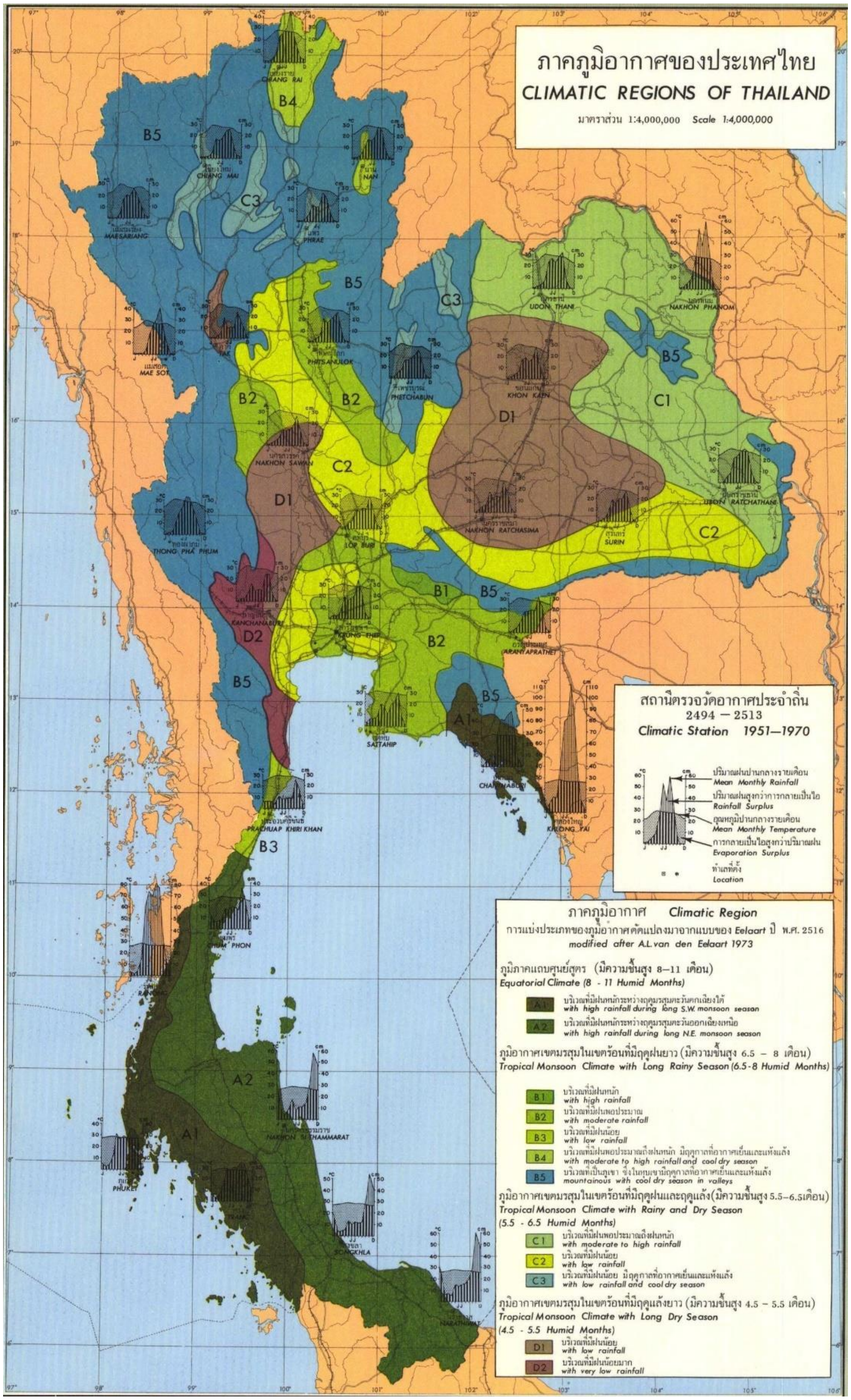


Figure 2.27: Climatic Regions of Thailand, map from Royal Thai Survey Department (A.L. 1976)

2.3.6 Holocene Sea Level Change

The climatic data during the Late Holocene (3000 BP to the present) in mainland Southeast Asia is poorly known. Research in Vietnam's Red River delta indicates three climate cycles after 5,000 cal. BP: 1) a cool and wet climate period during 4,530–3,340 cal. BP, followed by a warm and dry phase during 3,340–2,100 cal. BP; 2) a cooling climate with wet circumstances during 2,100–1,540 cal. BP, followed by a warming phase from 1,540–620 cal. BP later changed to dry conditions at 830 cal. BP; and 3) a cool stage during 620–130 cal. BP, which was dry at 360 cal. BP but afterward changed to the present warm and wet climate (Li, et al. 2006).

Marine transgressions and delta progradation inhibited human settlement along the shoreline of mainland Southeast Asia during this period (Stark 2006). Holocene sea–level data in East and Southeast Asia vary due to uncertainly tectonic variability of the regions or recorded methodologies (Boyd and Lam 2004). These shoreline elevation data are crucial to understand the region’s stratigraphy and settlement patterns. In Vietnam, the mid–Holocene maximum elevation is 3.25 m above present local sea level (Boyd and Lam 2004). Sea levels in northern Vietnam dropped and stabilized to present levels (+1.5 m) around 2,000 years ago (Boyd and Lam 2004). In Japan, the estimate of mid–Holocene maximum sea level is ca. +5 m around 5,500 to 6,000 BP (Umitsu 1991). In the Thai–Malay peninsula, the mid–Holocene maximum sea level is ca. +5 m around 5000 years ago, afterward it fluctuated until reached +2.5 m at 4,000 years ago (Tjia 1996). In the East China Sea and Java (at 6,000 to 5,000 years ago) is relatively low elevation ca. +3 m (Rimbaman 1992; Saito 1998). In southern Vietnam, the Bangkok Plain, and southern China, the mid–Holocene maximum elevation is intermediate ca. +4 m (Boyd and Lam 2004; Somboon 1988).

The Chao Phraya delta yields two dates for mid Holocene sea–level maxima of 6,500–7,300 BP and 3,800–3,900 BP (Boyd, et al. 1996; Somboon and Thiramongkol 1992). Sinsakul (2000) examined the marine deposits along Chao Phraya delta where the Chao Phraya River interacted with marine processes as the sea level changed during the Holocene transgression. The sea reached its maximum height of 4 m above the present mean sea level (MSL) around 6,000 BP and covered most of the present Chao Phraya delta as far as north of Ayutthaya (Sinsakul 2000; Somboon and Thiramongkol 1992). However, based on pollen evidence and radiocarbon dating of samples from Lower Central Plain, Hutangkura (2014) presented a different Holocene maximum transgression period, which is ca. 8,500-8,400 cal. BP or 6,500-6,400 BCE (Hutangkura 2014). His study indicates that the shoreline around 6,500-6,400 BCE was located in the area of present-day Suphan Buri and Ang Thong, and that most parts of the Lower Central Plain were flooded by the sea (Hutangkura 2014). Afterward, sea level on both the Thai–Malay peninsula and the Chao Phraya delta fluctuated until it stabilized and reached its present level around 1,500 BP or 500 CE (Boyd and Lam 2004; Sinsakul 2000; Tjia 1996; Woodroffe 2000). The Lower Central Plain consists of soft marine clay with an average depth of 15 m in the Bangkok area (Sinsakul 2000). This Plain is now tidal flats and mangrove swamps which has caused by the tidal–flat progradation and tide–dominated delta deposits (Sinsakul 2000).

There has been controversy over whether Dvāravatī sites (6th– 11th centuries CE) in the Central Plain were ancient coastal settlements with ports, or were swampy inland settlements. The first idea was hypothesized by Supajanya and Vanasin (1980, 1984) using aerial photographs, remote sensing technique, as well as topographical analysis and locational data for ancient cities from Takaya's (1972) (Hutangkura 2014; Supajanya and Vanasin 1984; Supajanya and Vanasin 1980; Takaya 1968). They identified 63 sites scattered within the Lower Chao Phraya Plain and no sites located below the shoreline elevation at the level of 3.5-4 m (Supajanya and Vanasin 1980). They proposed that during 6th century CE shoreline must have been situated further inland, about 130 km to the north of the present coastline, and claimed that their Dvāravatī sites were located along the edge of this palaeo-coastline (Vanasin and Supajanya 1980). Many historians and archaeologists, for instance Mudar (1999), Saraya (1999), and Khunsong (2010), accepted this proposal and interpreted U Thong, Ku Bua, and Nakhon Pathom as coastal sites (Figure 2.11). However, based on marine geology, pollen analysis, and dating evidence indicated that Supajanya and Vanasin proposed coastline closely matched that of the Holocene maximum transgression at 6,000 BP (Somboon and Thiramongkol 1992), or 6,500-7,300 BP (Somboon and Thiramongkol 1992), or 8,000-7,000 BP (Tanabe, et al. 2003; Umitsu, et al. 2002), or 8,500-8,400 cal. BP (Hutangkura 2014) (Figure 2.28).

Nevertheless, based on the geological, pollen, spore, diatoms, and marine deposit evidences, several scholars (e.g. Kanjanajuntorn 2006, Gallon 2013, Hutangkura 2014, and Songtham, et al. 2015) disagree with the coastline proposed by Supajanya and Vanasin. They argued that sea level on the Chao Phraya delta reached its present level around 1,500 BP which was roughly the same time as the emergence of Dvāravatī culture. During this time, a mangrove belt covered most of palaeo-shoreline of the Lower Central Plain and limited human habitation since the deltic plain was too young, had low sediment, and experienced seasonal floods. Therefore, Dvāravatī sites were only established on the terrace area of the Lower Central Plain (Hutangkura 2014).

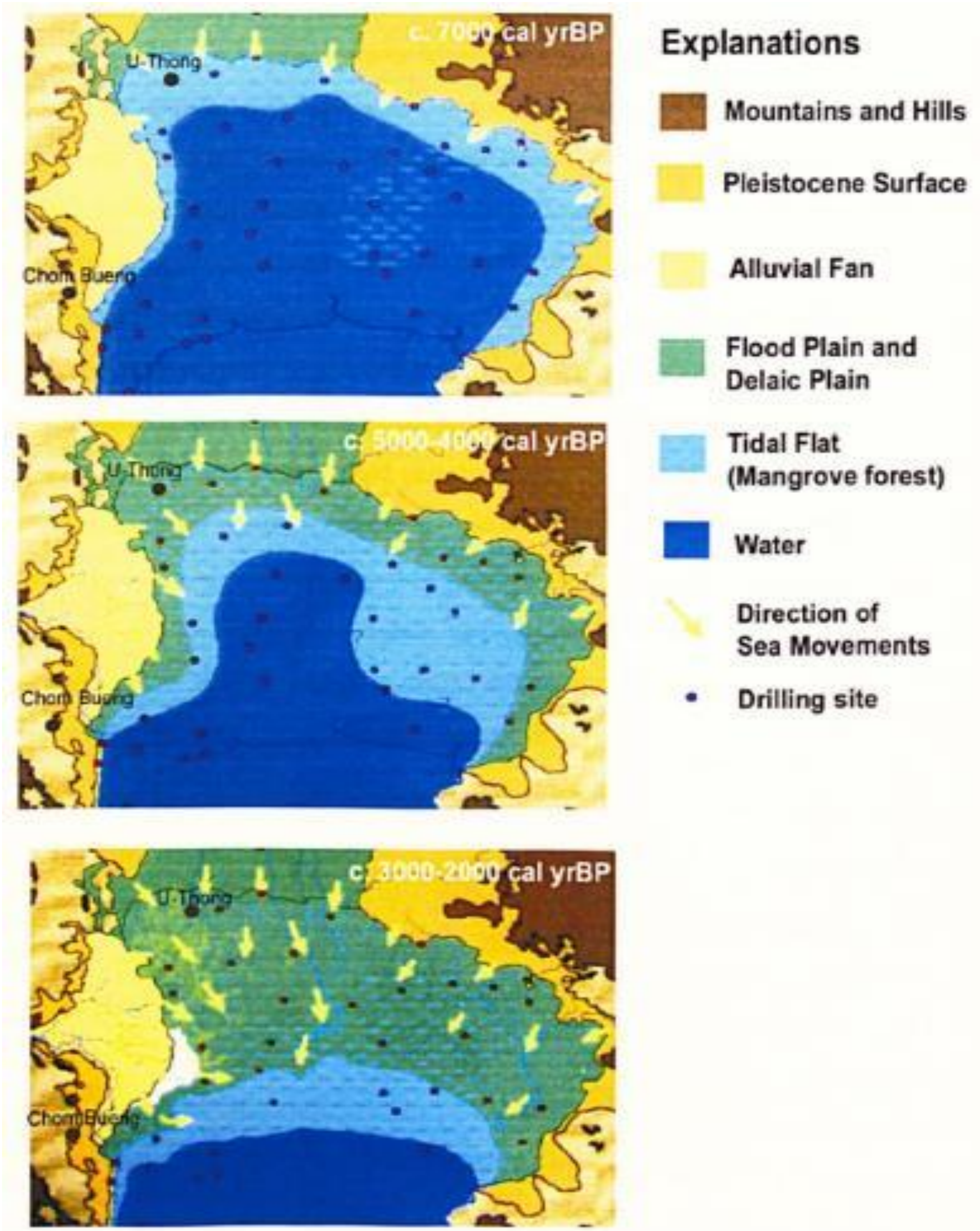


Figure 2.28: Diagrams on evolution of the Central Plain and sea level changes along the Gulf of Thailand, after Umitsu et al. 2002 and Kanjanajuntorn 2006

The Lower Central Plain gradually developed after the Holocene maximum transgression ca. 8,000-7,000 BP. No evidence of human settlements has been detected until around 2,000 years ago because this area was dominated by swamps and wetlands with a thick vegetation of sedges and other monocotyledonous plants (Songtham, et al. 2015). Dvāravatī culture was the first record of historic human settlement in this area. Several Dvāravatī sites were situated along the 8,000-7,000 BP ancient coastline and further inland. Consequently, Vanasin and Supajanya (1980) concluded that these Dvāravatī sites were seaports (Songtham, et al. 2015). The actual coastline during Dvāravatī period was relatively close to the present-day sea level and could not have expanded northward beyond Bangkok as well as could not have extended to Dvāravatī sites (Songtham, et al. 2015). Most Dvāravatī sites are located around the Chao Phraya delta hence they would not have been coastal settlements, but could have continued access to the Gulf of Thailand and maritime trade using rivers, tributaries, or canals that cut through the massive swamps and wetlands (Gallon 2013). These major sites include Ku Bua (Ratchaburi), Nakhon Pathom, U thong (Suphan Buri), Kheetkhin and U Ta Pao (Saraburi), Dong Lakhon (Nakhon Nayok), Si Mahosot (Prachinburi), and Muang Phra Rot (Chonburi) (Figure 2.29). Most Dvāravatī sites are located 5 m above MSL (Pramojanee and Jarupongsakul 1995), except the Buddhist monument at Thung Setthi. This site is merely 4 km away from the modern shoreline (Barram and Glover 2008). Gallon (2013) measured the elevation of the ground surface around the monument by using GPS, providing an elevation of 4.6 m above MSL (Gallon 2013).

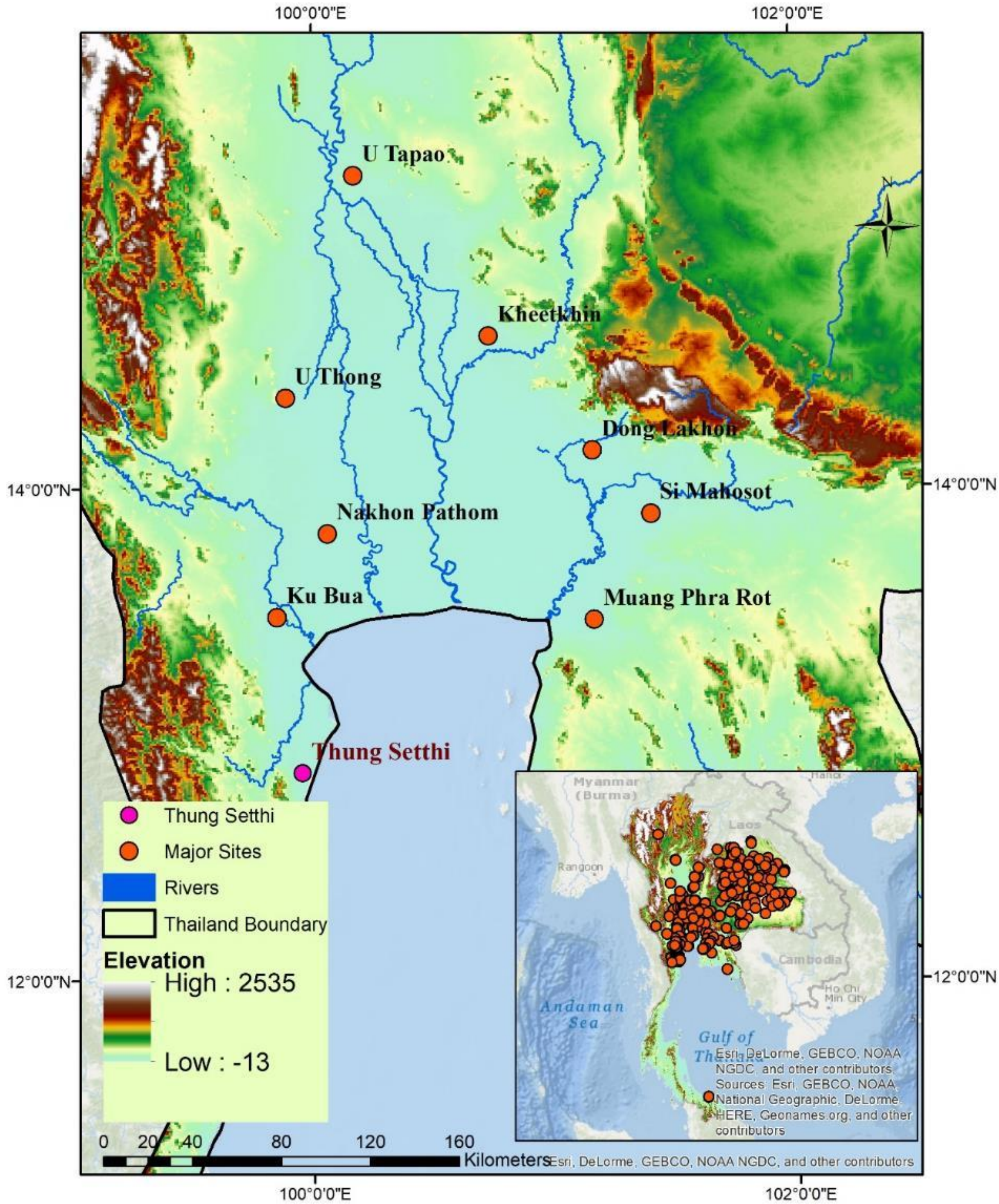


Figure 2.29: Map of the Lower Central Plain showing major Dvāravatī sites located along terrace of ancient mid-Holocene maximum transgression (ca. 8,000-7,000 years old), map by Areerut Patnukao, basemap from Esri, NOAA, and other contributors

2.3.7 Defining Geographic Levels in This Study

To better understand the spatial distribution and pattern of these sites, the spatial distribution and pattern of Dharmacakras and Dvāravatī sites are analyzed based on three different geographic levels, which are national, regional, and river basin level. At the national level, all sites were analyzed based on the whole country's area to understand the overall picture of Dvāravatī settlement. At the regional level, the sites were analyzed based on six geographic regions to search how different geographic landscapes correlate with these sites. Finally, these sites were analyzed based on river basins to identify which river basin is the most preferable to settle.

2.4 The Rise of Social Complexity and Civilization in Southeast Asia

The transformation from relatively simple society into complex civilization in Southeast Asia was once thought to be a result of external forces such as Indian and Chinese influences. The concept 'Indianization' in Southeast Asia refers to the transfer of Indian cultural influences through immigrants, colonizers, or traders in the 2nd century CE (Boyd, et al. 1999a; Boyd, et al. 1999b). Several complex technologies and knowledges were introduced by India, including non–animistic cosmological religions, concepts of kingship and government, writing, the planned towns, and irrigated wet rice agriculture, as well as social and political hierarchy (Welch 1985). Alternatively, revisionist scholars from 1970s proposed that the rise of social complexity among the Iron Age was a result of both internal dynamics and external cultural contacts (Boyd, et al. 1999a; Boyd, et al. 1999b; Welch 1985). These scholars emphasized that the local societies were more active than passive acceptance of Indian culture (Hall 2011; Higham 2004; Welch 1985; Wolters 1999). Their studies show that Southeast Asians were directly engaged in the consumption, distribution, and production of prestige objects, which contrasts with an early idea that Southeast Asians were passive in trade networks (Hall 2011). In addition, Southeast Asian civilizations were not extensions of India and China, but as a result of indigenous organization (Hall 2011). These indigenous communities responded to the external cultures by adapting and synthesizing them, not displacing them (Hall 2011). Recently, archaeologists have revealed that the roots of cultural complexity in Southeast Asia extend far back in time, before the rise of civilization in India or China, but they have different views about the factors of this development (Bayard 1984; Higham 1998; Higham 2013; Higham and Thosarat 2012).

Wolters (1999) focuses on the study of activities of Southeast Asians. He noted that local people responded to the traders and other foreigners by optimizing their opportunities (Wolters 1999). His idea contrast with an earlier idea proposed by George Coedès, which presented that the state formation was a result of Indian cultural interaction (Coedès 1968). Unlike Coedès, Wolters and other revisionist scholars studied specific areas within the region rather than the large region as a whole (Hall 2011). This method provided more details which revealed the similarities and differences of results from area to area.

One of the most acceptable hypotheses for the rise of civilization in Southeast Asia has been presented by Higham and his research team. This is based on work done on mainland Southeast Asia, including in the Mekong, Red, and Chao Phraya River valleys, as well as on the Khorat Plateau. Higham et al. indicated that a major change in social organization arose in the mid–first millennium BCE (Higham 1998; Higham 2004; Higham 2011; Higham 2013; Higham, et al. 2015; Higham, et al. 1982). Carter (2013) also suggested that there was a great social shift time to the emergence of the first complex state–level societies in Southeast Asia during the Iron Age (Carter 2013). Prior to this period, settlements were autonomous, fairly small, and equal in size, and they were linked by widespread trade networks (Mudar 1999). The widely traded goods included marine shell, copper, axes, and salt (Mudar 1993). These sites were located along the margins of floodplains of large rivers and the middle courses of small streams (Mudar 1993).

After 500 BCE, settlements in several parts of Southeast Asia expanded and become more diverse, especially in the Red River Valleys of Vietnam and in the Khorat Plateau of Thailand (Mudar 1993). In first millennium CE, several large urban centers developed throughout Southeast Asia (Figure 2.30) (Stark 2006). These large centers focused on craft activities and intensified agricultures (Mudar 1993). Exotic goods were used to represent and advertise high social status (Mudar 1993). The evidence in burials showed that during the Iron Age, communities in Southeast Asia began to develop a centralized authority, massive labor projects, large settlements, and hierarchical social status (Carter 2013; Higham 2004).

Higham (2004) suggested that the critical factor of emergence of complex societies is the availability of new technology, exclusively iron and wet rice. He pointed out that the availability of iron blades permitted double cropping of rice fields and water control allowed for surplus rice production. Food surpluses led to the establishment of regional centers, which could increase various types of specialists and local populations, attract outsiders, and create social hierarchy (Higham 2004). This hypothesis has been proposed to describe the emergence of chiefdoms in northeast Thailand and Vietnam (Mudar 1993).

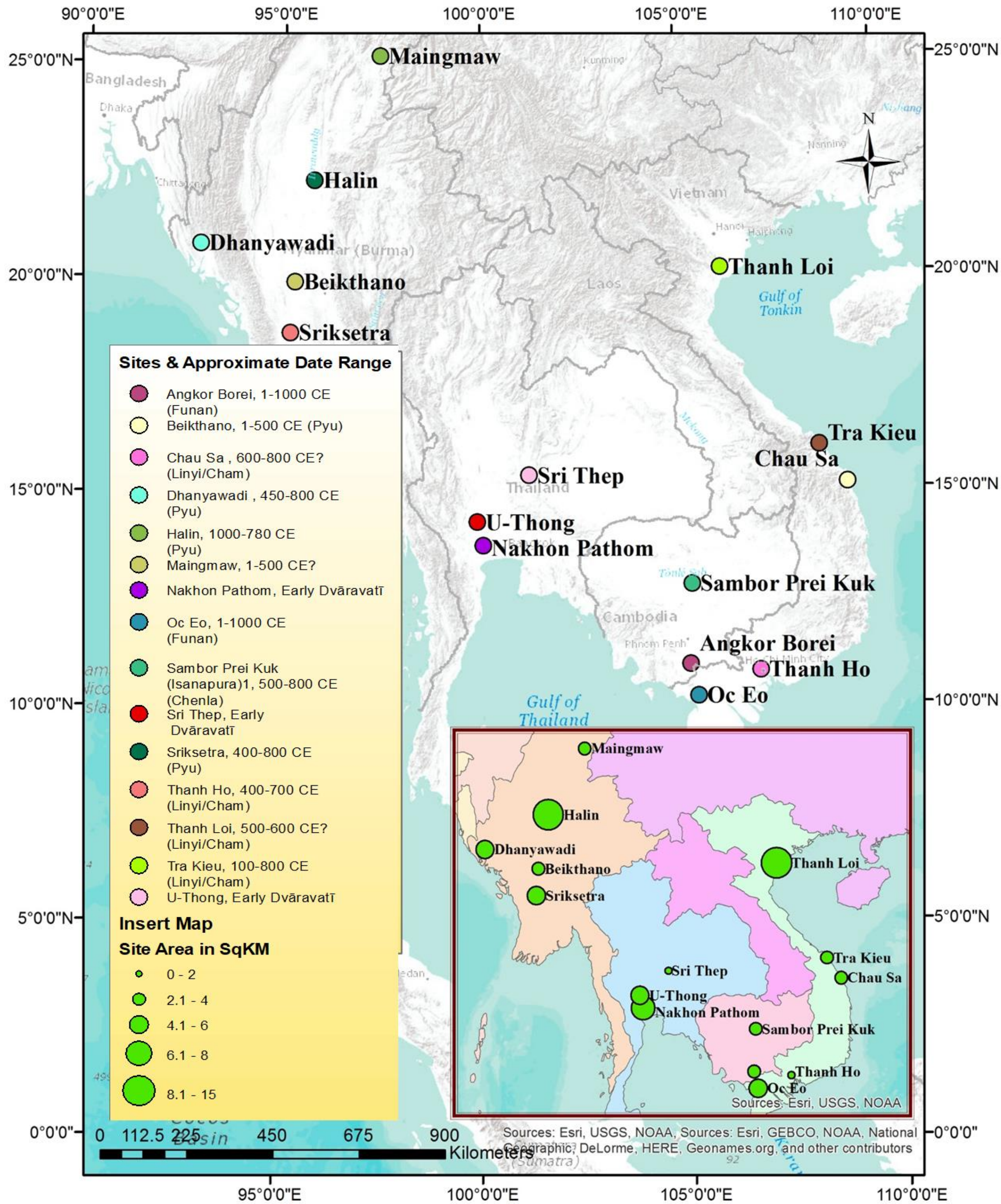


Figure 2.30: Site locations and sizes of selected early centers in mainland Southeast Asia occupied in the millennium CE (from Stark 2006: Table 1 and Gallon 2013 Table:7.1), map by Areerut Patnukao, basemap from Esri, USGS, NOAA, GEBCO, and other contributors

However, there are numerous factors that may lead to the emergence of complex societies or states in Southeast Asia. The integration of history, archaeology, geography, and social sciences has developed several approaches and theoretical models to the study of the remote past (Christie 1995). These approaches and models include ecological models and warfare by Carneiro (1970), peer–polity interaction by Renfrew (1986), the coastal trade interregional interaction and exchanges by Freidel (1979), the hydraulic societies by Wittfogel (1957), and the concept of state and kingship in Southeast Asia by Heine–Geldern (1942) (Carneiro 1970; Freidel 1979; Heine-Geldern 1942; Renfrew and Cherry 1986; Wittfogel 1957). To understand the rise of civilization in this region, these models need to be considered in future research.

2.5 The Emergence of Social Complexity in Early Thailand

The concept of the emergence of sociopolitical complexity refers to the appearance of ranked societies or hierarchy, such as chiefdoms or states (Carter 2013; White 1995). Recent research in northeast Thailand has emphasized the complex process of emergence of social complexity (Carter 2013; Higham and Thosarat 2012). Higham and Kijngam (1982) proposed an initial model for the emergence of centralized chiefdoms based on research in the Chi River Valley in northeast Thailand (Higham, et al. 1982). The evidence was based on the existence of larger moated sites than others in the same region, which might signify a two–tier settlement hierarchy (Carter 2013; Higham, et al. 1982). A range of factors might have supported the growth of these larger sites. For instance, sites situated near major river systems may have controlled trade routes from the Chao Phraya Valley in central Thailand, and these trade networks might have brought metal technologies, which could support agricultural development (Carter 2013). Growing populations could have also stimulated warfare and competition between different settlements (Carter 2013).

Recently, research in the Mun River Valley of northeast Thailand has added supplementary data. The data include Iron Age burials such as excavations at Ban Non Wat (Higham and Thosarat 2012). Theses burials demonstrate the increasing quantities of personal wealth in the form of beads, ceramics, and gold, silver, and bronze ornaments (Carter 2013; Higham 2011). The control over these new exotic items could have enhanced social status within a community or lead to the emergence of leaders (Higham 2011). Penny (1984) suggested, that in terms of cultural development, the emergence of social complexity Iron Age Thailand reflected the prosperity brought about by rich subsistence resources, which produced surplus to the needs of the village–based culture. The prosperity of the region assured local people could interact with external trading networks and in turn, it attracted the outsiders (Penny 1984). The demand for exotic and luxury items by emerging elite groups may promote external interaction and spatial expansion (Penny 1984). The moated sites of the Mun and Chi river valleys in northeast Thailand have shown spatial expansion in response to population growth and central place organization across the Khorat Plateau (Penny 1984). Therefore, development of interregional and international exchange networks should be seen as a result of increasing sociocultural complexity (Boyd, et al. 1999a; Boyd, et al. 1999b). In addition, the use of buffalo water for wet rice cultivation, water storage, and agricultural tools changed land–use (Kealhofer and Grave 2008). Moated sites are believed to indicate urban, and feasibly city–state, development from the latter half of the first millennium CE in central Thailand (Stark 2006).

In sum, the archeological evidence, including domestic rice agriculture and prehistoric ceramic technology, suggests that indigenous bronze and iron cultures of northeast and central Thailand developed contemporaneously with the civilizations in the Euphrates, Nile, and Indus River Valleys during the third millennium BCE (James 2003). However, those indigenous people of Thailand left no traces of inscriptions, language, stone or brick monuments, and temples or palaces as did the later proto–historic period (James 2003). Therefore, the study of evidences from Dvāravatī period such as the inscriptions on the Dharmacakras, settlement patterns, together with other evidences such as stone or brick monuments and complexes, Buddhist artifacts, and records of the Chinese pilgrims, might facilitate the visualization and reconstruction of the developments from primitive societies to urban complexities in this region.

2.6 The Use of GIS in Archaeology

Geographic Information System (GIS) is one of the greatest tools for analysis and display archaeological records at every spatial scale (Moyes 2002). Archaeologists use several methods and procedures from different disciplines such as geography and statistics to analyze and derive spatial information from archaeological sites. GIS is a powerful and efficient decision–making tool for spatial datasets and archaeological data (Davies 2006). GIS provides the ability to integrate multiple layers of information simultaneously, which is providing archaeologists with a new means for interpreting landscapes. GIS is emerging as a fundamental tool for archaeological theory (Wescott and Brandon 2000). The application of GIS in archaeology began in the 1970s (Wheatley and Gillings 2002). At first, GIS was used for the analysis of artifact densities or patterns of site distribution within a region. In the 1980s, archaeologists used GIS as a tool to study the environment and social interactions (Wheatley and Gillings 2002). The adoption of GIS in the mid–to–late 1980s, and especially the suitability of the raster data structure, which facilitated the application of predictive modeling at a regional scale, reinforced the methodology so strongly that theoretical development in other areas of landscape archaeology were largely overridden (Wheatley and Gillings 2002).

GIS is used to complete many research goals. For example, McKillop (2009) investigated the distribution of ancient Maya wooden architecture on the sea floor by using GIS together with archaeological methods, such as field survey (McKillop 2009). Zhang et al. (2010) used GIS and archaeobotanical survey to analyze early Bronze Age settlements in the upper Ying valley, which is part of the China's central plain. This research provided useful data for understanding prehistoric arable ecology and farming during a period of increasing local social complexity (Zhang, et al. 2010). Bevan and Conolly (2002) combined GIS, landscape archaeology, and archaeology survey to study archaeological remains and settlement patterns on the island of Kythera, Greece (Bevan and Conolly 2002).

Spatial analysis is one of the most important GIS analyses. It has developed along the history of quantitative methods in archaeology (Conolly and Lake 2006). Generally, spatial analysis is the quantitative analysis of spatial phenomena. Spatial analysis has been defined as a method for analyzing spatial data on the Earth's surface and serves as a tool to support spatial decision–making (Fischer and Wang 2011). The relative location of people and places is considered to be a central idea of geography (Johnston and Sidaway 1997).

Many of the foundations of spatial analysis were established by quantitative geographers in the 1950s and 1960s, and adopted and modified by archaeologists in the 1970s and 1980s (Conolly and Lake 2006). Afterward spatial analysis was considered an obsolete method both in archaeology and other social sciences due to a shift towards more oriented and relativist studies of human behavior (Conolly and Lake 2006). Later, however, spatial analysis was renewed because of the increasing interest in the techniques of spatial analysis in order to understand the spatial organization of human behavior (Conolly and Lake 2006) . Recently in archaeology, the use of spatial analysis methods to study human behavior has been increasing (Conolly and Lake 2006).

The main concept of spatial analysis is based on relative and proximal locations that create spatial relationships (Elsalam 2011). Bailey and Gatrell (1995) introduced three general types of spatial analysis tasks which are exploratory data analysis, visualization, and model building (Bailey and Gatrell 1995). There are the numbers of spatial analysis methods such as linear regression; spatial autocorrelation; cluster analysis (e.g. Nearest Neighbor Analysis and Ripley's K); density analysis (e.g. Kernel Density Estimates); local functions; and predictive modeling (Conolly and Lake 2006).

Archaeologists use several methods and procedures from different disciplines, such as geography and statistics, to analyze and derive spatial information from archaeological sites. Difficulties in spatial analyses ranges from simple map overlay operations to statistical models (Bailey and Gatrell 1995). Statistical methods play an important role in archaeology in various ways. Archaeological research typically begins by generating samples and terminates by generalizing about the population from which the sample was drawn (Thomas 1978).

However, the application of GIS to archaeological study in Thailand and other areas in Southeast Asia is in the initial stage. Recent projects include Lertlum et al. applying remote sensing and GIS to study the historic environmental condition at Sukhothai, Si Satchanalai, and Kampaeng Phet World Heritage Sites (Lertlum, et al. 2004). Lertlum et al. (2012) launched the "Living Angkor Road Project." This project used remote sensing, GIS, archeological methods and cultural information to identify all the remaining portions of ancient roads radiating from the Angkor capital to different provinces of the ancient Khmer Empire, which are located both in Cambodia and Thailand (Lertlum, et al. 2012).

In this research, GIS technology was used to manage, analyze, and display the spatial pattern of Dharmacakra locations and Dvāravatī settlements.

2.7 Spatial Statistics in Settlement Patterns Analysis

Settlement analysis in archaeology has appeared since the early 1950s as a main research approach for examining prehistoric social, political, economic structure, site pattern, and social organization (Wilen 1982). This approach treats the sites themselves as artifacts (Wilen 1982). Settlement analysis falls into two broad approaches: 1) ecological, where settlement patterns are investigated as environmental location; and 2) sociological, where settlement patterns are investigated as social relationships, religious organization, economic structure, and political organization (Trigger 1968). Basically, settlement and spatial archaeology employ the past activities and the characteristics of these locations. The various types of archaeological settlements are considered as preserved facets of a past society (Wilen 1982). Through spatial analysis, site locations could reveal picture and characterization of various activities, behaviors, networks, and cultural relationships.

The aim of using settlement analysis in archaeology is to investigate the spatial distribution of material culture and human modifications of the landscapes in order to understand the cultural and environmental processes of human settlement systems (Fletcher 2008). The analysis tools consist of linear or logistic regression and nearest neighbor or quadrat analysis (Fletcher 2008). These quantitative methods are used to investigate correlations between settlement and social or environmental variables, or the degree to which new settlements are located in physical relation to existed settlements (neighborhood dependence) (Bevan and Conolly 2006). However, these quantitative methods may cause problems since the linear or logistic regression can mislead in contexts where spatial dependence can be shown to exist, while nearest neighbor or quadrat analyses are poor at spotting multiscalar spatial patterns (Bevan and Conolly 2006).

Settlement distributions are often described in terms of their patterns, namely random, regular/dispersed, or clustered (Hodder and Orton 1976). Random distribution has no structured pattern, and has usually been treated as the statistical null–hypothesis (Fletcher 2008; Hodder and Orton 1976). A regular or uniform pattern has been used to reflect a degree of competition between settlements, the existence of site catchments, or both (Fletcher 2008; Hodder and Orton 1976). This pattern usually has a service center or central place for exchanging food and products, as well as serving as administrative or religious centers (Hodder and Orton 1976: 55). A clustered pattern may be caused by several factors, such as localized resources and the emergence of polities or regional centers, as well as uneven survey or excavation (Fletcher 2008; Hodder and Orton 1976). Practically, settlement patterns are more complex, and changing scale of analysis could affect the patterns.

In this research, both global and local statistical methods were used to analyze data. The global measure methods, including Nearest Neighbor Analysis (NNA), give information on the hierarchized organization within a defined zone. The global model assumes that variation is the same everywhere. However, it may be the case that a global model does not represent variation at any individual location. Global methods make use of all available data, whereas local methods are often defined as those that make use of some subset of the data (Lloyd 2010). Local methods such as Kernel Density Estimation (KDE) makes it possible to analyze a structure from a particular point and to emphasize more details in the geographical variations of the fractality (Sanders 2013). For several decades, local models have been used widely in some disciplines. For example, it has been used in image processing local filters to smooth or sharpen images (Lloyd 2010). Additionally, KDE has been popularly used in archaeology. For instance, Somers and McKillop (2004) used kernel density to analyze the different types of ancient Maya artifacts found at Arvin's

Landing site on the south coast of Belize in order to examine the ancient cultural activity (Somers and McKillop 2004).

2.7.1 Nearest Neighbor Analysis (NNA)

The analysis of spatial point patterns came to prominence in geography during the late 1950s and early 1960s, when a spatial analysis paradigm began to take firm hold within the discipline. Geographers borrowed this method from plant ecology; afterward, it was used to analyze spatial patterns and applied in other contexts. The methods that were used could be classified into two broad types (Haggett et al. 1977). The first were distance-based techniques, using information on the spacing of the points to characterize pattern (usually, mean distance to the nearest neighboring point). Other techniques were area-based, relying on various characteristics of the frequency distribution of the observed numbers of points in regularly defined sub-regions of the study area ('quadrats') (Gatrell, et al. 1996). Typically, methods sought to establish departures from complete spatial randomness. Whereas this might prove a sensible benchmark in some cases, in others (such as examining the distribution of disease or the locations of retail outlets in urban areas) it is unlikely to prove illuminating. These methods refer to the important concept of complete spatial randomness; the methods seek solely to establish non-randomness (Haggett et al. 1977).

Nearest neighbor analysis is famously used for identifying clustered or regular distributions. Clark and Evans (1954) first used of this method for ecological purposes to analyze the spatial distribution of plant species. They developed a method for comparing the observed average distance between points and their nearest neighbors with the distance that would be expected between nearest neighbors in a random pattern (Clark and Evans 1954; Fletcher 2008; Rogerson 2014). This method was then applied to study settlement patterns (Clark and Evans 1954;

Fletcher 2008; Haggett 1977). This method is popular for archaeologists because it is straightforward to calculate and provides a simply coefficient interpretation (Fletcher 2008). Nearest neighbor analysis is significantly influenced by the size of the study area. The result can be random, regular, or cluster which depends on the amount of surrounding area (Hodder and Orton 1976). However, nearest neighbor analysis can only detect spatial patterning at the 1st nearest neighbor, which may overlook complex, multiscalar, and spatial patterns (Bevan and Conolly 2006).

The concept of nearest neighbor analysis, the nearest event $\mathbf{x}_i$ to a given event $\mathbf{x}_j$, is obtained using Pythagoras' theorem (Lloyd 2010):

$$d(X_i - X_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

The nearest neighbor statistic, *R*, is defined as the ratio between the observed and expected values:

$$R = \frac{R_o}{R_e} = \frac{\bar{d}}{\frac{1}{2\sqrt{\rho}}} = 2\bar{d}\sqrt{\rho}$$

R_0 is observed average distance between points and their nearest neighbors. R_e is the expected distance between points and their nearest neighbors when points are distributed randomly. Naturally, if R_0 is small relative to R_e, the pattern will be clustered; if R_0 is large relative to R_e, the pattern will be more dispersed than random (Rogerson 2014).

R_0 can be calculated as:

$$\sum_{i=1}^{n} \frac{d_i}{N}$$

where N is the number of points in the study area, and where d_i is the distance from point *i* to its nearest neighbor.

R_e is calculated as one over twice the square root of the density of points:

$$R_e = \frac{1}{2\sqrt{\rho}} = \frac{1}{2\sqrt{\frac{N}{A}}} = 0.5\sqrt{\frac{A}{N}}$$

where ρ is the density of points, and A is the size of the study area.

The mean nearest neighbor distance (d_{NN}) is given by:

$$d_{NN} = \sum_{i=1}^{N} \sum_{i \neq j=1}^{N-1} \frac{Min(d_{ij})}{N}$$

where Min*(d_{ij})* is the distance between each point and its nearest neighbor, N is the number of points in the distribution

If the distribution of points is completely spatially random. This is the *mean random distance* (or the mean random nearest neighbor distance, $d_{NN(ran)}$) or R_e. It is defined as:

$$R_e = d_{NN(ran)} = 0.5\sqrt{\frac{A}{N}}$$

where A is the area of the region and N is the number of incidents. Since A is defined by the square of the unit of measurement (e.g., km^2, m^2, etc.), it yields a random distance measure in the same units (i.e., km, m, etc.) (Levine 2013).

The value of R varies from 0 to 2.14 when a value of R=0 means a value obtained when all points are in one location, and the distance from each point to its nearest neighbor is zero. If a value of R is less than 1.0, it shows a clustered pattern. A value of R = 1 indicates a random pattern, since the observed mean distance between neighbors is equal to that expected in a random pattern (Rogerson 2014). Conversely, if the value of R is greater than 1.0. This would be evidence for dispersion, that points are more widely dispersed than would be expected on the basis of chance

(Levine 2013). A value of R=2.14 means a perfectly uniform or systematic pattern of points maximally spread out on an infinitely large two-dimensional plane (Rogerson 2014).

Tests of the Significance

Clark and Evans (1954) proposed a Z-test to indicate whether the observed average nearest neighbor distance was significantly different from the mean random distance (Clark and Evans 1954). If the value of R shows that a given population is not randomly distributed, the significance of the departure of d_{NN} from $d_{NN(ran)}$ can be tested by the normal curve.

The test is between the observed nearest neighbor distance and that expected from a random distribution and is given by:

$$Z = \frac{d_{NN} - d_{NN(ran)}}{SE_{d(ran)}}$$

d_{NN} is the mean nearest neighbor distance.

$d_{NN(ran)}$ is the mean random nearest neighbor distance.

where the standard error of the mean random distance is approximately given by:

$$SE_{d(ran)} \cong \sqrt{\frac{(4-\pi)A}{4\pi N^2}} = \frac{0.26136}{\sqrt{\frac{N^2}{A}}}$$

with A being the area of region and N the number of points. There have been other suggested tests for the nearest neighbor distance as well as corrections for edge effects (Levine 2013).

2.7.2 Kernel Density Estimate (KDE)

Spatial patterns on the earth’s surface can be produced by physical or cultural processes. These patterns represent the spatial distribution of a variable across a study area. Sometimes geographic variables are displayed as point patterns with dot maps. Kernel estimation is a generalization of this idea, where the window is replaced with a moving three-dimensional function (the kernel) which weights events within its sphere of influence according to their distance from the point at which the intensity is being estimated. The method is commonly used in a more general statistical context to obtain smooth estimates of univariate (or multivariate) probability densities from an observed sample of observations. Estimating the intensity of a spatial point pattern is similar to estimating a bivariate probability density (Gatrell, et al. 1996).

Kernel Density Interpolation or Kernel Density Estimation (KDE) is a technique for generalizing incident locations to an entire area. KDE is an interpolation technique that is appropriate for individual point locations. While the spatial distribution and hot spot statistics provide statistical summaries for the data incidents themselves, interpolation techniques generalize those data incidents to the entire region. These techniques provide *density* estimates for all parts of a region (i.e., at any location). The density estimate is an intensity variable, a Z-value, that is estimated at a particular location. Consequently, it can be displayed by either surface maps or contour maps that show the intensity at all locations (Levine 2013).

KDE involves placing a symmetrical surface over each point, evaluating the distance from the point to a reference location based on a mathematical function, and summing the value of all the surfaces for that reference location. This procedure is repeated for all reference locations. It is a technique that was developed in the late 1950s as an alternative method for estimating the density of a histogram (Levine 2013). Silverman (1986) calculated required sample sizes for multivariate kernel estimators (see also Silverman 1986: Table 4.2: p.94). He specified the required level of accuracy for the density estimate at a single point at the center of a normal distribution. For example, for bivariate normal distributions with a relative mean squared error at a zero is less than 0.1, a required sample size is 19 (Silverman 1986).

KDE uses a filtering window to define neighboring objects. Within the window, KDE weighs nearby objects more than far ones. The method is particularly useful for analyzing and displaying point data. The occurrences of events are shown as a map of scattered (discrete) points, which may be difficult to interpret. KDE generates a density of the events as a continuous field, and thus highlights areas of concentrated events. The method may be also used for spatial interpolation (Wang 2014).

A kernel function looks like a bump centered at each point x_i and tapering off to 0 over a bandwidth or window (Figure 2.31). The kernel density at point x at the center of a grid cell is estimated to be the sum of bumps within the bandwidth:

$$\hat{f}(x) = \frac{1}{nh^d} + \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

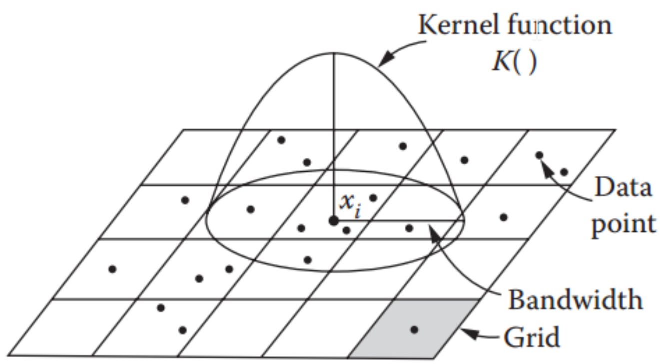


Figure 2.31: Kernel Density Estimation (Wang 2014:47)

where K() is the kernel function, h is the bandwidth, n is the number of points within the bandwidth, and d is the data dimensionality. Silverman (1986) provides some common kernel functions. For example, when d = 2, a commonly used kernel function is defined as

$$\hat{f}(x) = \frac{1}{nh^2\pi} \sum_{i=1}^{n} \left[1 - \frac{(x - x_i)^2 + (y - y_i)^2}{h^2}\right]^2$$

Where $(x - x_i)^2 + (y - y_i)^2$ measures the deviation in x–y coordinates between points (x_i, y_i) and (x, y).

The larger bandwidths tend to highlight regional patterns, and smaller bandwidths emphasize local patterns (Fotheringham et al., 2000:46). ArcMap has a built-in tool for KDE. The KDE tool can be accessed in ArcToolbox > Spatial Analyst Tools > Density > Kernel Density (Wang 2014).

Kernel Functions

There are a number of different kernel functions that have been used in applications. In *CrimeStat*, there are five alternative kernel functions that can be used, all of which have a circumscribed bandwidth (search area) (Figure 2.32) (see also Levine 2013). In this research, ***quartic*** function was used. The ***quartic*** function is applied to a limited area around each incident point defined by the radius, h. It falls off gradually with distance until the bandwidth radius is reached. Its functional form is:

1. Outside the specified bandwidth, *h*:

$g(j)=0$

2. Within the specified bandwidth, *h:*

$$g(i) = \sum_{i=1}^{M_j} \left[KW_i I_i \frac{3}{h^2 2\pi} (1 - \frac{d_{ij}^2}{h^2})^2 \right]$$

where $g(j)$ is the density of cell j, d_{ij} is the distance between cell j and an incident location, i, h is the radius of the search area (the bandwidth), K is a constant, W_i is a weight at the point location, and I_i is an intensity at the point location. The summation is for the incidents that are within the bandwidth. Thus, each cell, j, has a different number of incidents that fall within the bandwidth search area, M_j. In *CrimeStat*, the constant K is initially set to 1 and then re-scaled to ensure that either the densities or probabilities sum to their appropriate values (i.e., N for densities and 1.00 for probabilities).

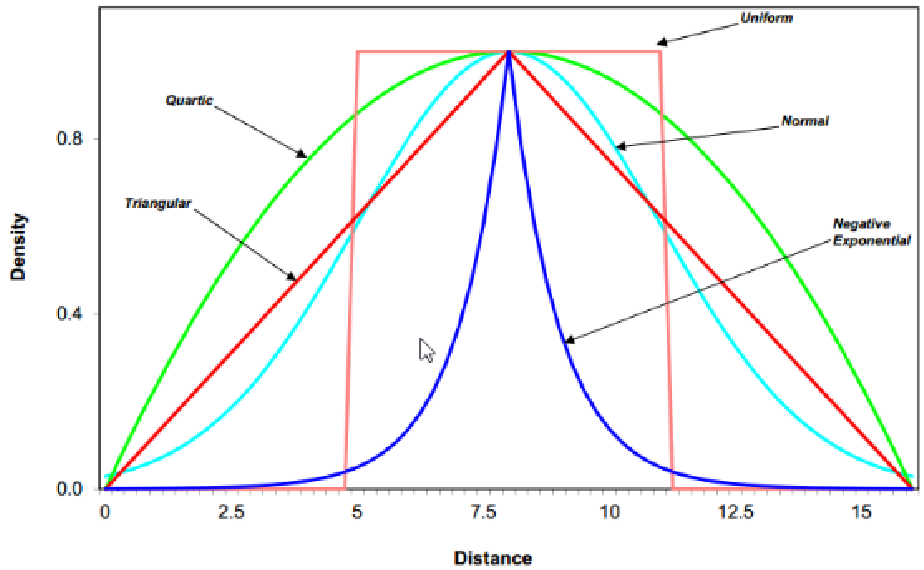


Figure 2.32: Five different kernel functions that are available in *CrimeStat*. (after Levine 2013: Figure 10.5)

2.8 Statistical Analysis

The statistical analyses in this study rely on archaeological site samples to understand the relationship between several variables (see variables in Table 3.7). JMP Pro 13 and Microsoft Excel were used for statistical analyses. Because of nonparametric sample data, the chi-square test was used to determine whether the relationship between the independent variables is significant or not.

Chi-Square Test

A Chi-square statistic measures the difference between the observed counts and the counts that would be expected if there were no relationship between two categorical variables. (Caldwell 2009). For this research, the null hypotheses (H_0) is there is no relationship between site and spatial variables. The level of significance is set at 0.05. Chi-Square formula presents below:

$$X^2 = \sum \frac{(Observed\ frequencies - Expected\ frequencies)^2}{Expected\ frequencies}$$

$$= \sum \frac{(F_o - F_e)^2}{F_e}$$

F_e = *Expected frequency*, F_o = *Observed frequency*

$$F_o = \frac{(row\ total\ x\ column\ total)}{gran\ total}$$

2.9 Settlement Size Distribution Analysis

A variety of techniques and models have been developed by geographers to analyze and explain settlements systems. Analyses that deal with the size distributions of settlements have been used extensively on modern settlement system, have appeared to be particularly applicable to archaeological data sets for several reasons. First, analysis of settlement size distributions does not require the rigid initial conditions and prior assumptions necessary using other geographical models such as central place theory. Size distribution analysis requires only the settlement system as a single operating unit and represents the total population comprising the system. Second, the settlement size is the principle variable that is used in size distribution analysis. Settlement size is considered as the most logical technique for determining the population of prehistoric settlements. Site size and location is the most adequate available measure of cultural response to the environmental variation (Mudar 1993). Settlement size is considered by most geographers and anthropologists to be a useful indicator of the number and kinds of activities carried out at a site (Haggett 1977). Within a settlement system, variation in sites can be considered as at least an initial indicator of possible variable in site function. Settlement size distribution are normally viewed in terms of the relationship between the size of a settlement and its rank. In the literature these are generally referred to as rank–size distribution (Haggett 1977).

Since the 1950's locational analysis has become an increasingly powerful for the study of social organization and social complexity. In the 1970's, catchment analysis and geographical models such as Central Place Theory increased the capabilities of settlement pattern analysis (Flannery 1976). More recent work (Johnson 1981; Renfrew 1975; Steponaitis 1981) has sought to expand these geographical models to address questions of economy in complex chiefdoms and early states. The organization of social and economic interactions is expected to be shown in the organization of settlements (Mudar 1993).

2.9.1 Rank Size Rule

The rank-size approach was adopted into regional settlement studies in archaeology from geography nearly 30 years ago (Drennan and Peterson 2004). Geographically, it has been used to analyze the population distribution across the settlements in a region. Settlement systems typically comprise comparatively few large settlements and a much greater proportion of smaller settlements. Settlement size-frequency distributions are normally leptokurtic and show strong negative skew (in the direction of small settlements) (Johnson 1981). A rank-size distribution is a simple way of viewing a size-frequency distribution. Settlements are descending ranked and settlement size (usually population size) is plotted against settlement rank in that descending array of sizes (Johnson 1981). The settlement rank and settlement size has normally been plotted as a line of the logarithms (Drennan and Peterson 2004). A few very high ranking settlements have a significant impact on the overall shape of the line on the graph, while many low-ranking settlements are crowded into the lower section of the line (Drennan and Peterson 2004).

The rank–size rule suggests that in well–integrated regional system a settlement of rank r in a descending array of settlement sizes will have a size equal to 1/r of the size of the largest settlement in the settlement in the system (Johnson 1981). For instance, rank 2 is half as large as rank 1; rank 3 is one-third as large as rank 1; and so on. This model relationship between a settlement size and rank is known as log-normal distribution. This distribution yields a straight line with a slope of –1. The result is a straight line on a logarithmic rank-size graph, running from upper left to lower right. This straight-line pattern has been named log-normal (Drennan and Peterson 2004) (Figure 2.33a).

Other patterns are regularly explained in terms of how they depart from the log-normal line. For instance, several large settlements with similar populations result in a convex pattern (Figure 2.33b). In a primate distribution, the large population of the largest settlement makes the graph drop rapidly below the log-normal line (Figure 2.33c). Additionally, several population variations depart from log-normal in different ways result in the combination patterns (Figure 2.33d).

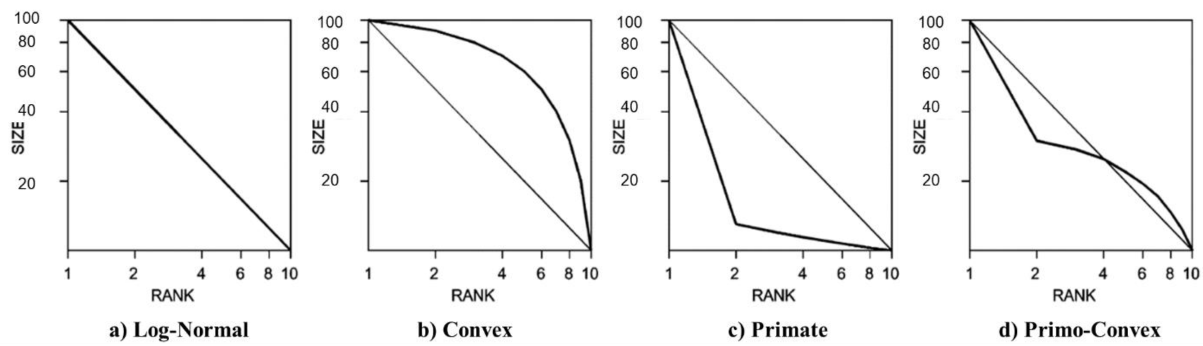


Figure 2.33: Examples of rank-size graph with different shapes (after Drennan and Peterson 2004: Figure 1)

Johnson (1981) notes that a primate settlement hierarchy can specify the presence of secondary states in a colonial relationship with another polity. Two basic types of distributions from rank-size analysis are primate and convex distributions. Primate (or concave) distribution occurs when the largest site in a settlement system is larger than the sizes of the other sites would predict. This may occur when economic competition is minimized for largest center. It may happen when the largest site differentially interacts with sites in other systems. Convex distribution is an indication of low integration between sites in the sample. It may indicate that the level of regional integration among the settlement is low (Johnson 1981).

The mathematical form of the rank-size rule was very simple. "In an ordered set of cities representing a given country, the product of the rank and size of a city is constant" (Dziewoński 1972:73). It may be expressed as following formula (Dziewoński 1972; Moore 1959):

$$P_i = \frac{P_l}{R_i^b}$$

Where P_l = Population of the largest city, P_i = Population of the "ith" city, R_i = Rank of the "ith" city, and b = A constant

Initially the constant "b" was thought to be uniform (Beckmann 1958; Kingsley 1949). The rank-size distribution has been explained in terms of the Pareto distribution and in the usual form for rank-size rule, b is assumed equal to 1 (Beckmann 1958). It has been claimed that the rank-size rule (with b=1) is a good working approximation to hierarchy of cities (Moore 1959). However, it seems that it varies and depends on the "state" of the settlement system in question (Moore 1959; Pearson 1980).

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the materials and research methods used to establish database of Dvāravatī sites and Dharmacakra locations database, to analyze the distribution of sites and Dharmacakras' locations, and to reconstruct the environmental setting of these sites. The final step is to analyze the relationship between the motifs and styles of Dharmacakras and their environmental setting. The chapter starts by discussing the research approach, followed by a flow chart that illustrates the work procedure used. The data collection, data sources, and field survey are discussed. A database, including Dharmacakras and Dvāravatī sites from secondary sources as well as field survey was created in spreadsheet format. The spatial and statistical analysis softwares including ArcMap10.3, Excel, CrimeStat 4.02, Surfer 10, and JMP Pro 13 played important roles to analyze the data to answer research questions and to test hypotheses.

3.1 Research Approach

This study applied both qualitative and quantitative methods to collect, analyze, and present the data. The study is primarily based on three main approaches: documented data collection, field survey, and pre–and–post data processing. The spatial distribution and patterning of Dharmacakras and Dvāravatī sites are analyzed based on three different geographic levels which are national, regional, and river basin level to understand the spatial distribution and pattern of these sites (see Figure 3.1). The research procedures include data input, pre–processing data, and spatial and statistical analysis (see Figure 3.2). The input data are obtained from field survey and secondary data from different sources.

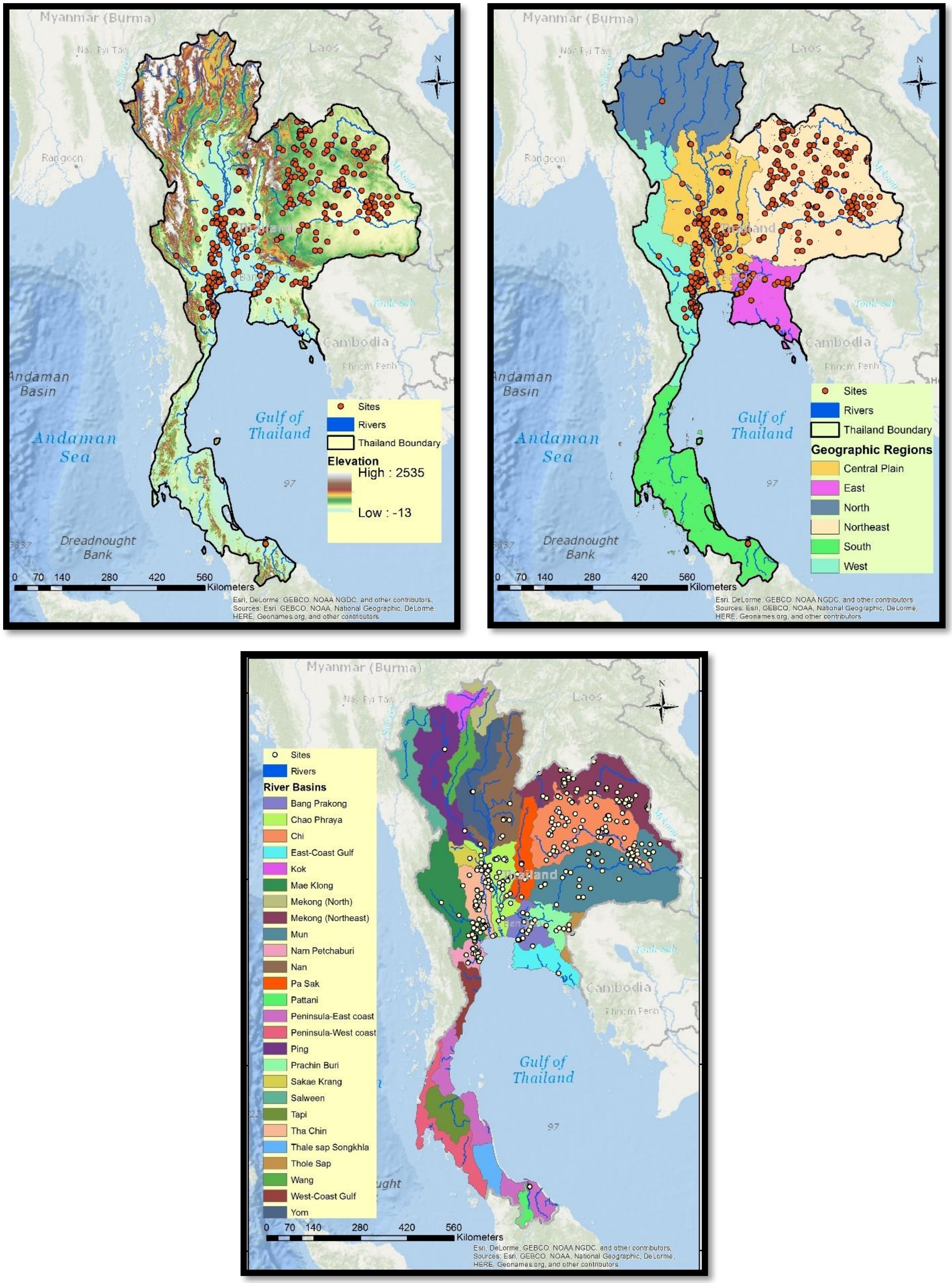


Figure 3.1: Three different geographic levels of spatial distribution analysis; national level (Upper Left), geographic regional level (Upper Right), and river basin level (Bottom)

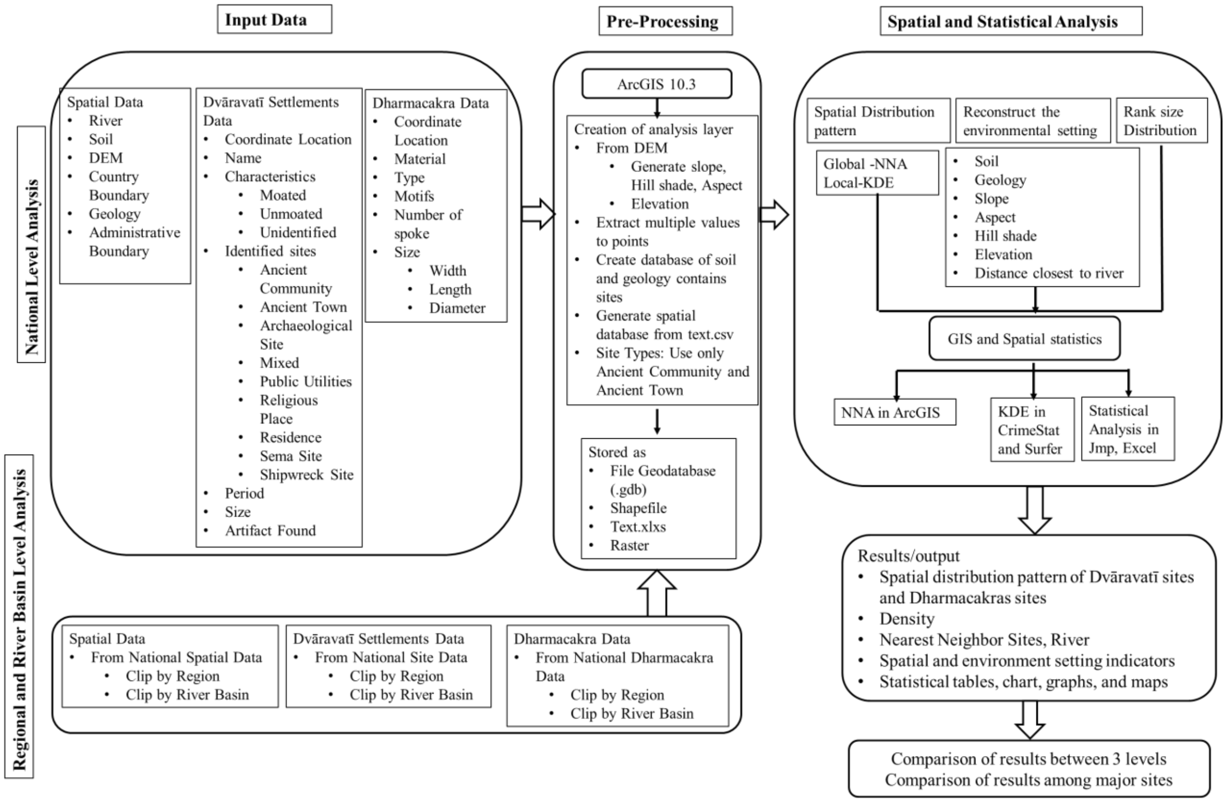


Figure 3.2: Research Procedures

The data are categorized into three different sets which are spatial data, Dvāravatī settlement data, and Dharmacakra data. These data sets were input and organized in spreadsheet format. The data pre–processing was manipulated in ArcMap 10.3. This step prepared and classified data to be ready for analyzing in different tasks. For instance, to reconstruct the ancient environmental settings of the sites, several layers were created and stored as File Geodatabase (.gdb) format and assigned different names. The slope, hill shade, and aspect were extracted from Digital Elevation Model (DEM). The final step is spatial and statistical analysis. This step applied different spatial statistical methods to analyze the data. For example, the distribution pattern of Dvāravatī sites and Dharmacakra locations were analyzed in two different levels: Nearest Neighbor Analysis (NNA) and Kernel Density Estimate (KDE). In addition, other statistical analyses were performed to better understand, for instance, the relationship between sites and spatial variables such as slope, aspect, elevation, soil, and geology type. The comprehensive details are presented in section 3.3.

3.2 Materials

3.2.1 Data Collection and Source

The data sets used in this study were obtained from several sources described below. The data of Dharmacakras and major Dvāravatī sites were derived from field survey in Thailand and secondary data sources. Field survey data include coordinate positions, physical environments, elevations, and photos of Dharmacakras and Dvāravatī sites. The secondary data were derived from previous research and dissertations. Other materials for analysis were retrieved from a variety of sources (Table 3.1).

3.3 Methods

The archaeological approach used in this research can be largely defined as landscape archaeology, particularly considering that the field survey is a regional survey as opposed to a site specific one. This study tries to explain and understand the distribution of Dharmacakras in terms of the religious, political, and geographical landscapes within which they existed. Furthermore, the spatial distribution of Dvāravatī sites and environmental setting would be tested. Additionally, the relationship between the distributions of Dharmacakras and Dvāravatī settlements was investigated. A number of statistical analyses such as a chi–square is employed to investigate the relationship between Dharmacakras and settlements. Spatial statistics methods and geographical models, including cluster analysis (Nearest Neighbor Analysis), density analysis (Kernel Density Estimates), and rank–size analysis are used to test the pattern, distribution, and hierarchical order of Dvāravatī settlements.

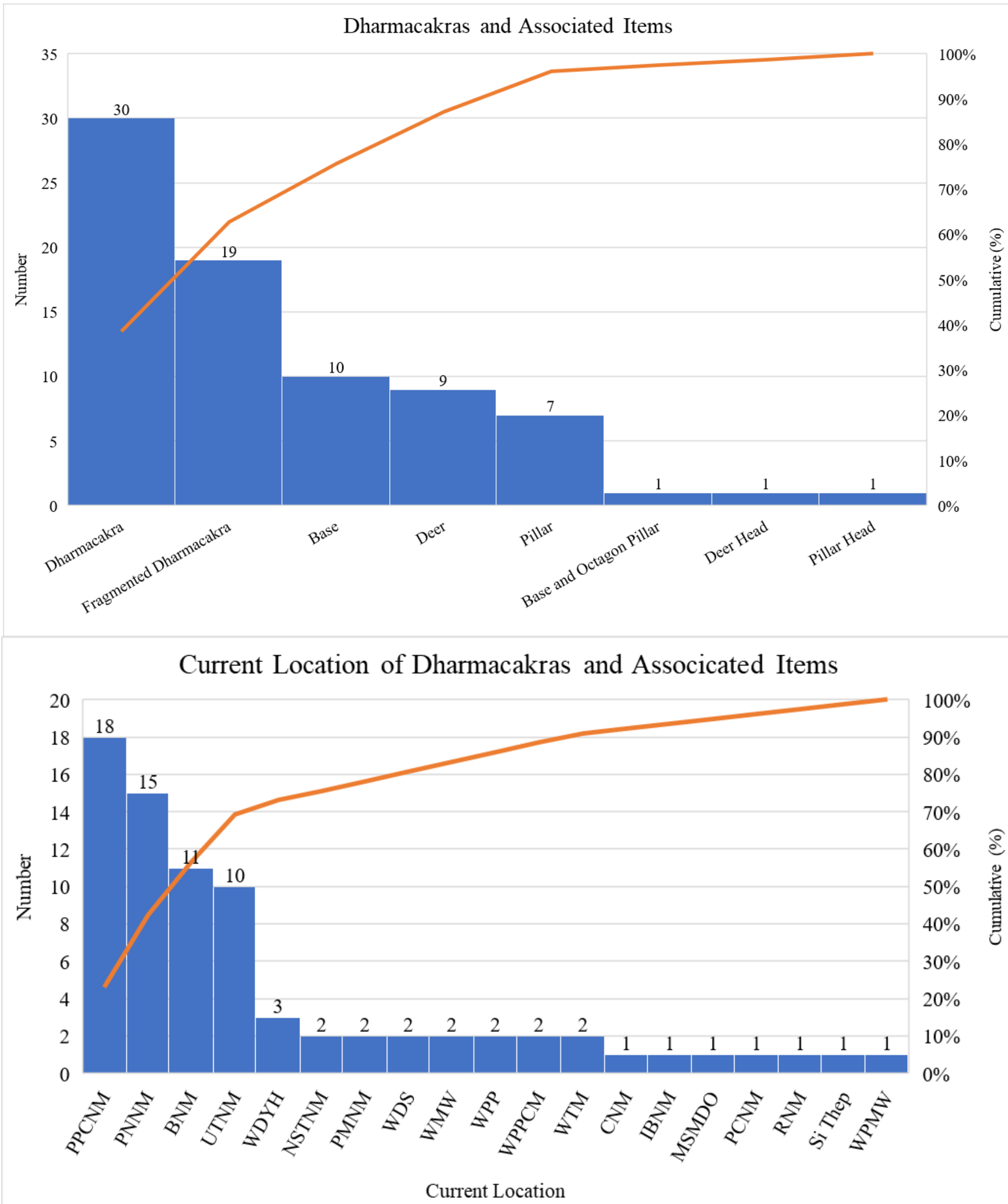
Table 3.1: List of data and sources used in analysis

#	Data Type	Details and Sources
1	Administrative boundary	Digital data obtained from Ministry of Transport, Thailand
2	Rivers	Digital data obtained from Ministry of Transport, Thailand
3	River Basin	Manually digitized from map of 25 river basins in Thailand obtained from Department of Water Resources, Thailand (www.dwr.go.th/contents/files/article/article_th–27012012–162728–85852.pdf)
4	Geology	Digital data obtained from Department of Mineral Resources, Thailand
5	Digital Elevation Model (DEM)	DEM (ASTER) with resolution 30 meter obtained from U.S. Geological Survey (https://gdex.cr.usgs.gov/gdex/)
6	Aspect	Extract from DEM 30 meter
7	Hillshade	Extract from DEM 30 meter
8	Slope	Extract from DEM 30 meter
9	Elevation	Extract from DEM 30 meter, crosscheck with Google Earth 2017
10	Soil	Digital Soil Map of the World from FAO UNESCO (http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116#)
11	Dharmacakra Locations	Field Survey December 2015 – February 2016 in Thailand
12	Dharmacakra Studies	Wales (1969), Ito (1978), Brown (1981, 1996), Yupho (1990), Saisingha (2000), Indrawooth (2008), Indorf (2014)
13	Dvāravatī Site Locations	Supajanya and Vanasin (1980, 1984), Indrawooth (1999), Pisnupong (1999), Mudar (1993, 1999), Thammarungruang (2015), Fine Arts Department (FAD) (http://gis.finearts.go.th/fineart/), Princess Maha Chakri Sirindhorn Anthropology Centre (SAC) (http://sac.or.th/databases/archaeology/สมัย–วัฒนธรรม/สมัยทวารวดี.)
14	Moated Settlement Studies in Thailand	Thesis: Clarke (2012), Welch (1985), Moore (1986), Mudar (1993), Gallon (2013), Murphy (2010)
		Research: Boyd, et al. (1999), Higham, et al. (1982), O'Reilly (2014), Supajanya and Vanasin (1980, 1984), Wilen (1982), Indrawooth (2004)

3.3.1 Field Survey

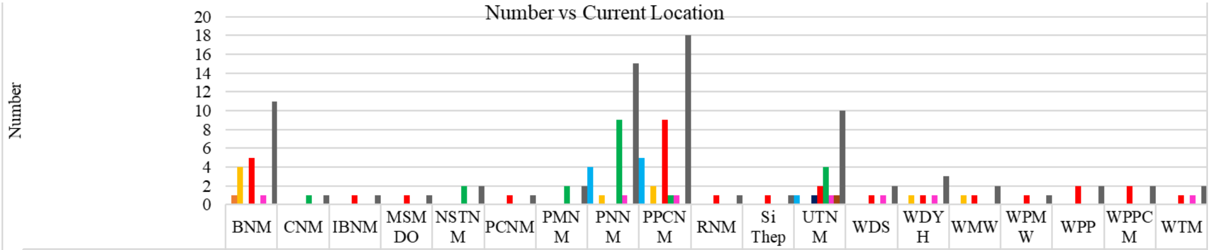
The field survey was conducted during December 2015– February 2016 in Thailand. Because there is no available online database of artifacts in national museums, all national museums were contacted to verify whether they have stored Dharmacakras and associated items (deer, pillar, base) or not. Afterward, the letters of permission were sent to 12 national museums across the country to request permission to access the data collection. Each museum visit was scheduled in advance.

The area of survey covered almost all museums and sites where Dharmacakras were found, except the Pattani province and museums in foreign countries (e.g., US and France). The survey work was accomplished with the assistance a crew of 3–4 persons. In this field survey, 12 national museums, 13 temples (Wat), 12 sites, and 3 stone quarries were systematically visited, and information about sites was successfully solicited. Additionally, the specialists were interviewed. The following tools were used to perform the survey: hand–held GPS (Garmin Oregon 550) courtesy of Department of Geography, Faculty of Arts, Chulalongkorn University; digital SLR camera (Nikon D80); measuring tape; and written notation. The expeditions were carried out in four different areas, including Bangkok and three other routes (Appendix A). 78 artifact items were obtained from this survey (Appendix A, Table A.1). There are 49 Dharmacakras among items (Figure 3.3). Phra Pathom Chedi National Museum holds the greatest number of items, 18 items (Figure 3.3 and 3.4).



BNM = Bangkok National Museum , WPPCM = Wat Phra Pathom Chedi Museum, PPCNM=Phra Pathom Chedi National Museum, WDYH=Wat Don Yai Hom, UTNM=U Thong National Museum, IBNM=In Buri National Museum, PNNM=Phra Narai National Museum, PMNM=Phimai National Museum, WDS=Wat Dharmacakra Semaram, PCNM= Prachinburi National Museum, MSMDO= Muang Si Mahosot District Office, RNM=Ramkhamhaeng National Museum, WTM= Wat Tha Mai, WMW = Wat Mahathat Worrawihan, WPP=Wat Phet Pli, CNM=Chaiya National Museum, NSTNM=Nakhon Si Thammarat National Museum, WPMW=Wat Phra Mahathat Woramahawihan

Figure 3.3: Data from field survey: numbers of Dharmacakras and associated items (Top), current locations (Bottom)



	BNM	CNM	IBNM	MSM DO	NSTN M	PCNM	PMN M	PNN M	PPCN M	RNM	Si Thep	UTN M	WDS	WDY H	WMW	WPM W	WPP	WPPC M	WTM
Base								4	5			1							
Base and Octagon Pillar	1																		
Deer	4							1	2					1	1				
Deer Head												1							
Dharmacakra	5		1	1		1			9	1	1	2	1	1	1	1	2	2	1
Fragmented Dharmacakra		1			2		2	9	1			4							
Pillar	1							1	1			1	1	1					1
Pillar Head												1							
Grand Total	11	1	1	1	2	1	2	15	18	1	1	10	2	3	2	1	2	2	2

Figure 3.4: Current locations and number of Dharmacakras and associated items, data from field survey

Dharmacakras, bases, pillars, and crouched deer were recorded by assigning each item a specific number prefixed by the different uppercase letters (B=Base, C=Cakra, D=Deer, P=Pillar), follow by province, and location (either location found or current location), and number (e.g. DBB1 = Deer, from Bangkok, at Bangkok National Museum). These items also include their present locations, original site locations, and coordinates (Appendix A, Table A.1). Dharmacakra dimensions were measured and then type, style, artwork, and material were recorded and categorized based on the previous studies of Brown (1996) and Indorf (2014). A brief sketch and description of each Dharmacakra were made. After that, each Dharmacakra was photographed in high resolution by a digital SLR camera (see Appendix B for a database of Dharmacakras and associated items, and Appendix C for photos).

3.3.2 GIS Analysis

ArcMap 10.3 is the main tool used to analyze, manipulate, and store input data for further steps of analysis. Data collected from several sources and formats were input, reformatted, geo–referenced, complied, and processed in this software.

3.3.2.1 GIS Database Management

Spatial and attribute data from different sources and formats were input, created, and stored in ArcMap 10.3 software. To input data to work with GIS, the data need to be processed and transferred into compatible formats with GIS. The processes included data acquisition, reformatting, geo–referencing, and creating attribute tables. In this study, several types of data inputs were employed, including digitizing, keyboard input, and scanning (Figure 3.5). The spatial reference system used in this study is the Universal Transverse Mercator (UTM) WGS 84 zone 47N.

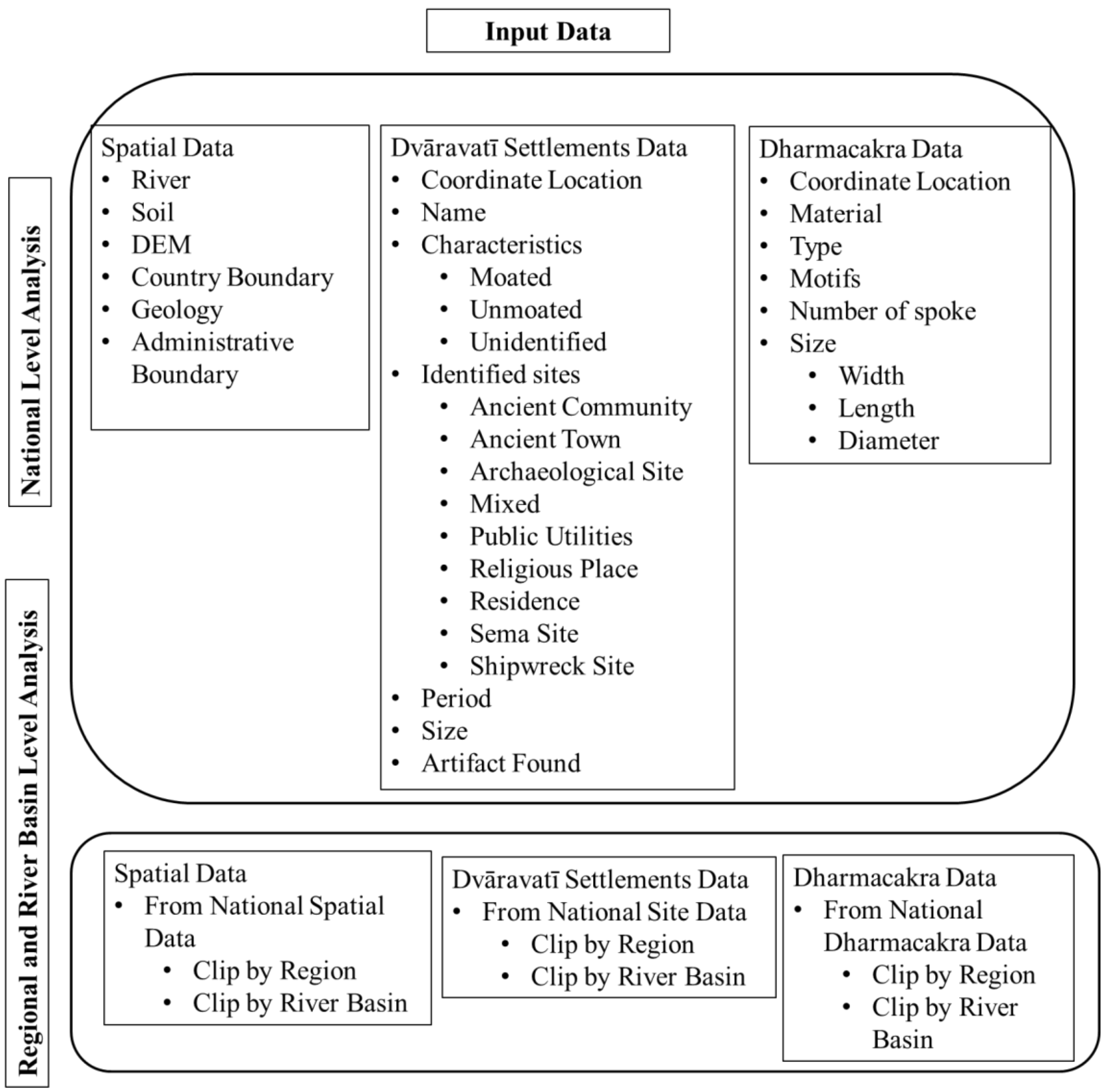


Figure 3.5: Data input framework

To reconstruct the geographic setting of Dvāravatī sites, the database of soil, geology, slope, hill shade, and elevation was created. However, the climate variables such as precipitation, temperature, and vegetation are not included in this model due to the limit on available data. In further research, these variables should be considered, including sea level change and other environmental conditions.

3.3.2.1.1 Data Input and Storage

Data input in this research can be categorized into three main sets; spatial data, Dvāravatī settlement data, and Dharmacakra data (see Figure 3.5). These data sets are managed to work with additional analyses in three different geographic levels, including national, regional, and basin levels (see Table 3.1 for data sources).

Table 3.2: Spatial data input

Data	Original Format	Input Method	Storage Format	Software	Function
Administrative and country Boundary	Digital shapefile	Add layer	Polygon.gdb	ArcMap 10.3	
River	Digital shapefile	Add layer	Polygon.gdb	ArcMap 10.3	
Soil	Digital shapefile	–Download from online source –Add layer	Polygon.gdb	ArcMap 10.3	
Geology	Digital shapefile	Add layer	Polygon.gdb	ArcMap 10.3	
DEM	Raster	–Download form online source in multiple files – Merge rasters	Raster		-Mosaic
River Basin	Paper	–Screen capturing –Digitizing	Polygon.gdb	ArcMap 10.3	-Geo-referencing -Editor

Table 3.3: Dvāravatī settlement and Dharmacakra data input

Data	Original Format	Input Method	Storage Format	Software	Function
Site Locations	–Paper –Online Database –GPS –Google Earth	–Keyboard entering –On screen digitizing	MS Excel.xlsx MS Excel.csv file.KML point.gdb point.shp	MS Excel ArcMap 10.3	
Size Area	–Paper –Basemap from ArcMap online	–Keyboard entering –Digitizing	MS Excel.xlsx MS Excel.csv polygon.gdb polygon.shp	MS Excel ArcMap 10.3	–Editor –Calculate geometry
Site Information	–Paper –Online Database	–Keyboard entering	MS Excel.xlsx MS Excel.csv		
Dharmacakra Information	–Paper –Online Database	–Keyboard entering	MS Excel.xlsx MS Excel.csv	MS Excel	

3.3.2.1.2 Data Classification

Site data are important to understand spatial distribution of settlement pattern and to comprehend the environmental setting of the site. This part of the database holds information regarding basic data on the Dvāravatī site, including: types of artifacts found, location, number of moats, size of site, site characteristic (e.g. moated, unmoated, or unidentified), and site type. Based on previous studies and secondary sources (Table 3.1), in this research, 425 sites were collected and presented. These sites were categorized into 9 major types based mostly on FAD and other works including Pisnupong (1999) and Murphy (2010). These 9 categories are Ancient Community, Ancient Town, Archaeological Site, Mixed, Public Utilities, Religious Place, Residence, Sema Site, and Shipwreck Site (Table 3.4). The classification of site types is not simply. Besides the well-studied sites, the rest of sites are ambiguous. For instance, some site types such as an Archaeological Site, Mixed, Public Utilities, Religious Place, or Residence are frequently located within an Ancient Town since it usually covers larger geographic area than other site types.

Therefore, in order to minimize redundancy of data, only two types of sites (Ancient Community and Ancient Town) are used to perform the spatial and statistical analyses (Table 3.5 and 3.6).

Based on the study of Pisnupong (1999), in this research, the Ancient Town means that the site is surrounded by moats or showed the traces of moats, while Ancient Community means that the site presents the evidence of human occupation, but it is not surrounded by moats. In the future research, all moated site locations and areas should be digitized into digital format (e.g. shapefile) in order to perform additional analyses such as to examine the number of site types within an Ancient Town or to test rank-size distribution.

Dvāravatī site data are input into a spreadsheet format. Each site is given a specific number prefixed by the uppercase letter which varies by region (C=Central Plain, E=East, N=North, NE=Northeast, S=South) followed by 'S' letter (S=Site), and number (e.g. CS1 = Central Plain region, Site#1) (Appendix D, Table D.1). Other data are input into spreadsheet and analyzed by using ArcMap 10.3 and excel.

Table 3.4: Number of Dvāravatī settlements sorted by types of site

Site Type	**Region**						**Total**	**%**
	Central Plain	**East**	**North**	**Northeast**	**South**	**West**		
Ancient Community	20	19				17	**56**	13.18
Ancient Town	50	9	1	15	4	4	**83**	19.53
Archaeological Site	40	2		28		27	**97**	22.82
Mixed	3	3		1			**7**	1.65
Public Utilities	1	9					**10**	2.35
Religious Place	16	7		9	1	7	**40**	9.41
Residence		1					**1**	0.24
Sema Site				128			**128**	30.12
Shipwreck Site	2	1					**3**	0.71
Total	**132**	**51**	**1**	**181**	**5**	**55**	**425**	100

Table 3.5: Ancient Community and Ancient Town in each region

Site Type	Region						Grand Total	%
	Central Plain	East	North	Northeast	South	West		
Ancient Community	20	19				17	**56**	40.29
Ancient Town	50	9	1	15	4	4	**83**	59.71
Grand Total	**70**	**28**	**1**	**15**	**4**	**21**	**139**	**100**

Table 3.6: Ancient Community and Ancient Town in each river basin

River Basin	Site Type		Grand Total	%
	Ancient Community	Ancient Town		
Bang Prakong	14	4	18	12.95
Chao Phraya	8	26	34	24.46
Chi		5	5	3.60
Mae Klong	11	4	15	10.79
Mekong (Northeast)		1	1	0.72
Mun		9	9	6.47
Nan		1	1	0.72
Pa Sak	2	4	6	4.32
Pattani		4	4	2.88
Phetchaburi	8	1	9	6.47
Ping		2	2	1.44
Prachin Buri	5	3	8	5.76
Sakae Krang	2	2	4	2.88
Tha Chin	6	13	19	13.67
Thole Sap		3	3	2.16
Yom		1	1	0.72
Grand Total	**56**	**83**	**139**	**100**

3.3.2.2 Data pre–processing

In this step, data were prepared for further analysis. Pre-processing data sets were processed by several tasks and operations as shown in Figure 3.6.

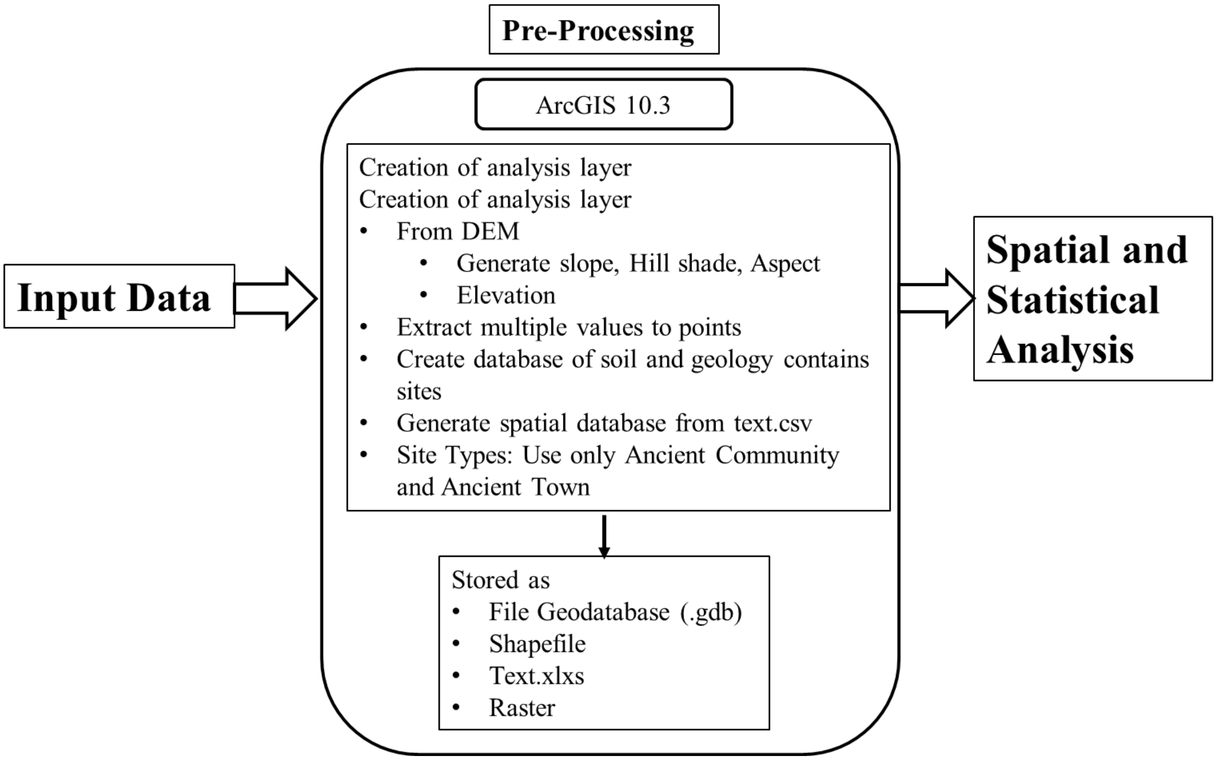


Figure 3.6: Data pre–processing framework

Extract values from DEM

Firstly, to reconstruct the geographic settings of Dvāravatī settlement, additional raster layers were generated from DEM, including Slope, Aspect, and Hillshade. Slope degrees were classified into six classes based on classification of Natural Resources Conservation Service, United States Department of Agriculture (NRCS, USDA) (Staff 2017) (see Figure 3.7). Aspect can be considered as slope direction. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of –1 (Figure 3.7) (Esri 2017a). The value of each cell in an aspect dataset indicates the direction the cell's slope faces. Aspect is useful to analyze the terrain based on factors that are influenced by aspect such as soil, ground moisture, and surface temperature. Hillshade grid is a grid of shadows for a specific time of day (specific azimuth and altitude of the sun). A hillshade analysis is a method to see where light would fall on a landscape. A hillshade raster is often used to show terrain to support other information in a map such as an analytical surface like settlement density, or a thematic overlay like geologies. By default, sun azimuth (direction) for hillshade is 315º and altitude is 45 degrees. In addition, shadow and light are shades of gray associated with integers from 0 to 255 (increasing from black to white) by default (Esri 2017c) (Figure 3.7).

Figure 3.7: The classification of slope (after Soil Science Division Staff 2017: Table 2-3, page 44), aspect, and hillshade extracted from DEM covered entire country

Afterward, the values of slope, aspect, hillshade, and elevation were extracted into point locations by using tools “Extract Multi Values to Points” (for slope, aspect, and elevation) and “Extract Values to Points” (for hillshade) in ArcMap 10.3 (see Figure 3.8). In this case, these values were extracted to Dvāravatī site locations (sites.gdb) and stored in the attribute table format. The elevation values extracted from DEM were later crosschecked with Google Earth 2017 to rectify some errors. These values extracted from DEM were classified into different groups in Table 3.7.

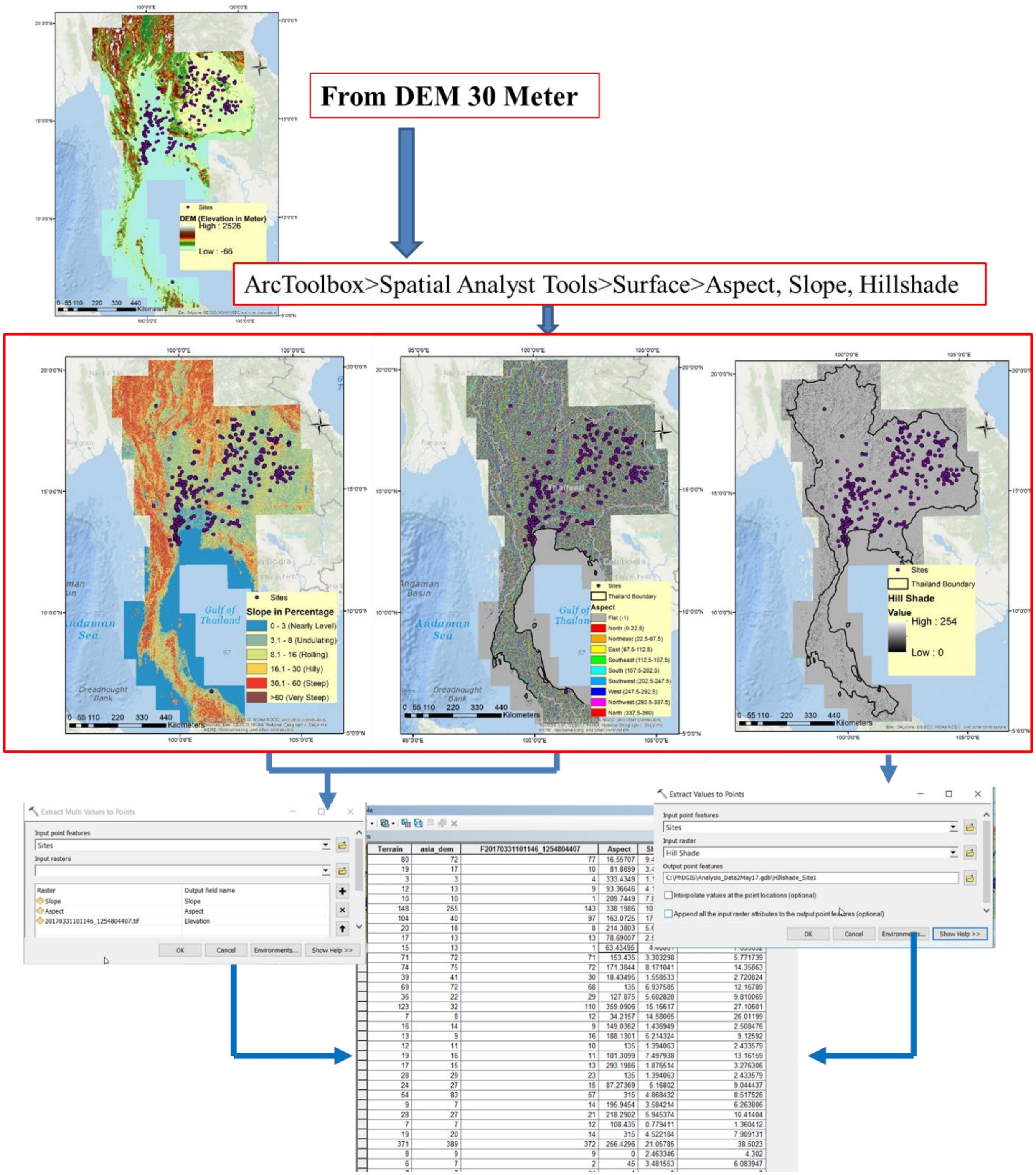


Figure 3.8: The process of generating aspect, slope, and hillshade from DEM respectively. Afterward these rasters were extracted values to the points and stored in attribute table of sites.gdb. The results from these analyses will be used in statistical analyses

Table 3.7: The outputs from DEM extraction

Aspect	**# of Site**	**Slope (%)**	**# of Site**	**Hillshade**	**# of Site**	**Elevation (m)**	**# of Site**
Flat	1	Nearly Level	23	120-150	4	0-50	97
North	17	Undulating	55	151-170	24	51-100	22
Northeast	23	Rolling	44	171-190	92	101-150	9
East	16	Hilly	11	191-210	16	151-200	9
Southeast	12	Steep	6	211-230	3	201-250	1
South	15	**Total**	**139**	**Total**	**139**	251-300	1
Southwest	26					**Total**	**139**
West	11						
Northwest	18						
Total	**139**						

Environmental variables within the sites

This section generates the environmental variables within the sites. The process starts from input basic characteristics regarding soil, geology, and river basins into ArcMap 10.3. To generate what types of soils, geologies, or river basins contain sites or how many sites are located in particular type of these environmental variables, the Select by Location function was used (see detail in Figure 3.9 and 3.10). In select by Location, the source layer is constant (the sites data set) while the target layers are changed (geology, soil, and river basin respectively). The spatial selection method for target layer feature is “intersect the sources layer feature”. Table 3.8 presents the output from this method.

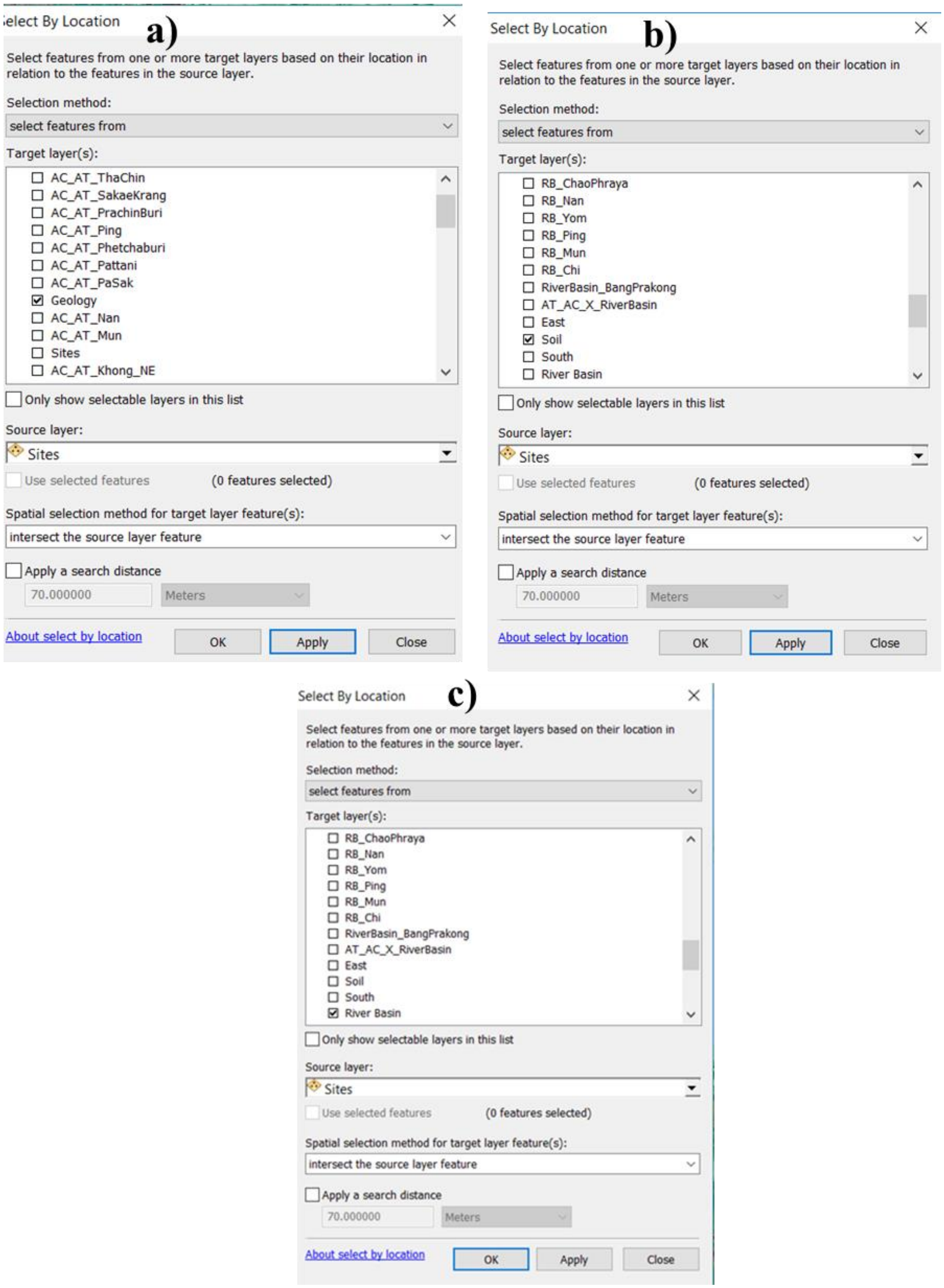


Figure 3.9: Select by location tool in ArcMap 10.3: a) geology intersect sites, b) soil intersect sites, and c) river basin intersect sites

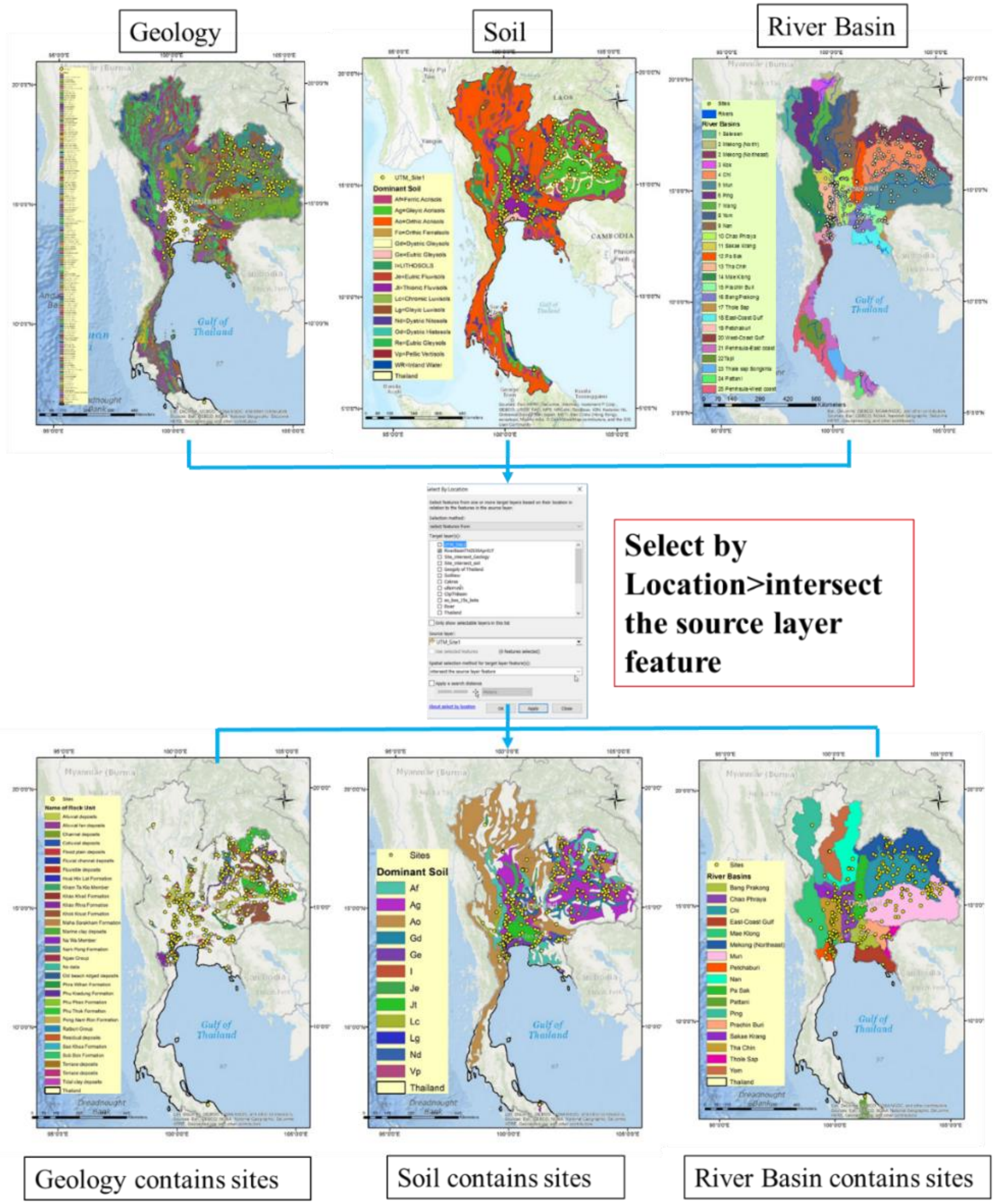


Figure 3.10: Environmental variables within the sites

Table 3.8: The outputs from select by location method

Geology	**# of**	**%**	**Soil**	**# of**	**%**	**River Basin**	**# of**	**%**
Neo Geology Formation	42	30.22	Af	10	7.19	Bang Prakong	18	12.95
Alluvial deposits	26	18.71	Ag	64	46.04	Chao Phraya	34	24.46
Alluvial fan deposits	1	0.72	Ao	2	1.44	Chi	5	3.60
Channel deposits	1	0.72	Gd	4	2.88	Mae Klong	15	10.79
Flood plain deposits	10	7.19	Ge	9	6.47	Mekong (Northeast)	1	0.72
Fluviatile deposits	13	9.35	I	1	0.72	Mun	9	6.47
Khao Khad Formation	2	1.44	Je	11	7.91	Nan	1	0.72
Khok Kruat Formation	2	1.44	Jt	11	7.91	Pa Sak	6	4.32
Maha Sarakham	3	2.16	Lc	2	1.44	Pattani	4	2.88
Marine clay deposits	1	0.72	Lg	1	0.72	Phetchaburi	9	6.47
Ngao Group	2	1.44	Nd	8	5.76	Ping	2	1.44
No data	7	5.04	Vp	16	11.51	Prachin Buri	8	5.76
Old beach ridged deposits	1	0.72	**Total**	**139**	100	Sakae Krang	4	2.88
Phu Thok Formation	2	1.44				Tha Chin	19	13.67
Pong Nam Ron Formation	1	0.72				Thole Sap	3	2.16
Ratburi Group	2	1.44				Yom	1	0.72
Residual deposits	11	7.91				**Total**	**139**	100
Sub Bon Formation	2	1.44						
Terrace deposits	6	4.32						
Tidal clay deposits	4	2.88						
Total	**139**	100						

Af = Ferric Acrisols, Ag= Gleyic Acrisols, Ao= Orthic Acrisols, Gd= Dystric Gleysols, Ge= Eutric Gleysols, I= Lithosols, Je= Eutric Fluvisols, Jt= Thionic Fluvisols, Lc=Chromic Luvisols, Lg=Gleyic Luvisols, Nd= Dystric Nitosols, Vp=Pellic Vertisols

3.3.3 Spatial Analysis

There are some limits on Dvāravatī settlement data, for instance, the accurate locations, number of moat, size, and type of sites. This section of analysis used only presently available data. This analysis aims to present as a pilot study. There might be more additional data available in the future which may alter the result of this study. At the beginning of the analysis, it is crucial to determine the number and types of the sites. In order to better understand the distribution of Dvāravatī settlement, only two types of sites included Ancient Town and Ancient Community were used. These sites are 139 out of 425 sites (Table 3.3 and 3.4). To analyze the spatial distribution of the sites, two techniques were implemented in different software programs. The first method is NNA, involved the discovery of patterns in the data based on spatial analysis in ArcMap 10.3. The second method is KED, used to identity the sites density based on the spatial analysis in CrimeStat 4.02 and Surfer 10.

3.3.3.1 Nearest Neighbor Analysis (NNA)

NNA is commonly applied in the analysis of point pattern. It is used to analyze the general spatial distribution of the data. The nearest neighbor distance for an event in a point pattern, is the distance from that event to the nearest event, also in the point pattern.

In this study, NNA is employed to determine whether the sites in three different geographic levels: nation, region, and river basin are clustered or dispersed. The NNA method is used to test the null hypothesis that the spatial pattern of Dvāravatī sites do not differ from complete spatial randomness and the sites are distributed independently. The NNA is computed by using Average Nearest Neighbor (ANN) tool in ArcMap 10.3.

The ANN tool in ArcMap measures the Euclidean distance between each site centroid and its nearest neighbor location. NNA is an average of these distances in the entire study area. If the average distance is less than the average for a hypothetical random distribution, the distribution of the sites being analyzed is considered clustered. On the other hand, if the average distance is greater than a hypothetical random distribution, the sites are considered dispersed. The ANN ratio is calculated as the observed average distance divided by the expected average distance:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E} \quad \text{where} \quad \bar{D}_O = \frac{\sum_{i=1}^{n}(di)}{n} \quad \text{and} \quad \bar{D}_E = \frac{0.5}{\sqrt{n/A}}$$

Where $\bar{D}_O$ is the observed mean distance of each site and its neighbor, $\bar{D}_E$ is the expected mean distance for the sites given in a random patter, *di* is the distance between site *i* and its nearest neighboring site, *n* is the total number of sites, and A is the area of a minimum enclosing rectangle around all sites (Esri 2017b).

The Nearest Neighbor Ratio (NNR) is the ratio between the Observed Mean Distance (OMD) and the Expected Mean Distance (EMD). NNR measures the degree of clustering or dispersion of the sites in each level. Value of NNR varies from 0 to 2.14 when a value of NNR=0 means sites are in one location, and the distance from each site to its nearest neighbor is zero. If a value of NNR <1 means sites are clustered. A value of NNR = 1 indicates a random pattern, since the observed mean distance between neighbors is equal to that expected in a random pattern (Rogerson 2014). On the other hand, if the value of NNR >1 means points are dispersed (Levine 2013).

The z-score and p-value are measures of statistical significance which identify whether to reject the null hypothesis or not. For ANN, the null hypothesis states that points are randomly distributed. The average nearest neighbor z-score for the statistic is calculated as (Esri 2017b):

$$z = \frac{\bar{D}_O - \bar{D}_E}{SE} \quad \text{where} \quad SE = \frac{0.26136}{\sqrt{n^2/A}}$$

Z-score is used to evaluate the significance between an observed and random distribution. If z > 1.96 or z < –1.96, it can be concluded that the calculated difference between the observed pattern and the random pattern is statistically significant given that α = 0.05. On the other hand, if –1.96 < z < 1.96, it can be concluded that the observed point pattern, is not significantly different from a random pattern, and it will fail to reject the null hypothesis. However, it should be noted that in ArcMap 10.3, if the value of a z-score is between -1.65 to 1.65, it results in random pattern. If z-score is greater than 1.65 indicates dispersed pattern. Alternatively, if z-score is less than -1.65 indicates clustered pattern.

In ArcMap 10.3, the ANN tool can be accessed in ArcToolbox> Spatial Statistical Tools> Average Nearest Neighbor (Figure 3.11). The results are presented and discussed in the subsequent sections.

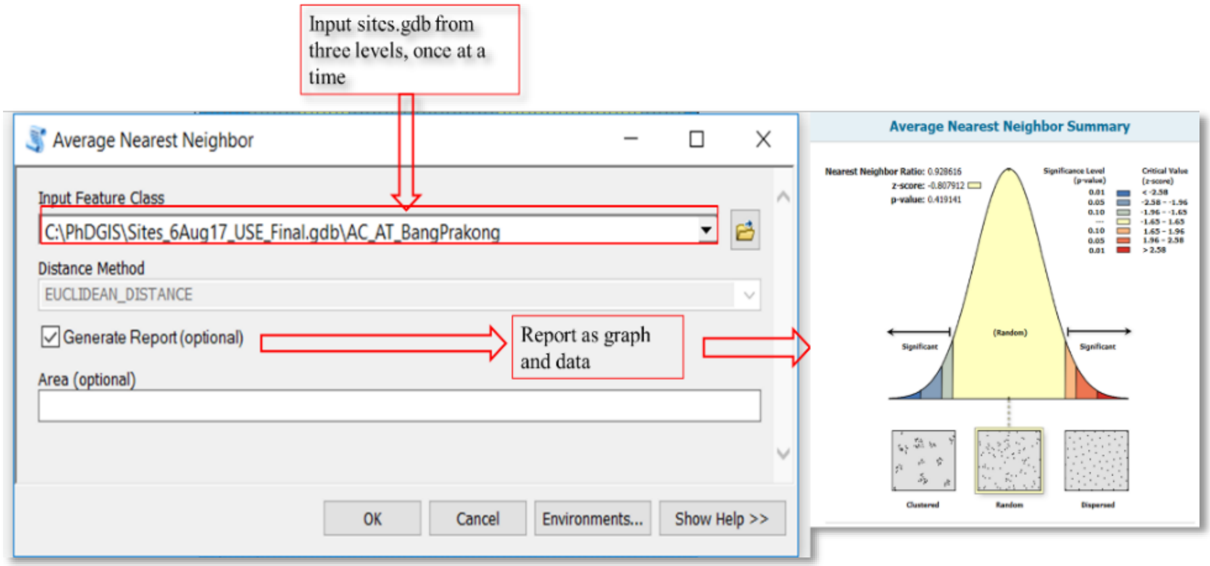


Figure 3.11: Average Nearest Neighbor (ANN) analysis in ArcMap 10.3

Dvāravatī Settlements

Before performing the NNA, 139 sites were generated into File Geodatabase format (.gdb) and analyzed in three different levels in ArcMap 10.3. At the nation level, these all sites were analyzed at one time. At the regional level, these 139 sites were sorted into six different regions. The sites in each region were then saved as six different (.gdb) files. Afterward these (.gdb) files are analyzed using Average Nearest Neighbor (ANN) tool. For the river basin level, only 16 of the 25 basins in Thailand that contained sites (Table 3.6). These sites again were sorted by basins and saved in 16 different (.gdb) files.

Dharmacakra Locations

Due to limited number of sites and precise locations, the Dharmacakra locations were analyzed only at the national level. Overall, there are 80 Dharmacakras. The field survey produced 49 items and 31 items came from previous studies (see Appendix B Table B.2). The analysis process is similar to those of Dvāravatī settlement.

3.3.3.2 Kernel Density Estimate (KDE)

KDE is employed to verify the degree of density and location of spatial data. In this study, it is used to determine the density degree of Dvāravatī sites. At the national level, 425 sites which include all site types, and 139 sites which are only Ancient Town and Community types were analyzed by KDE. However, based on Silverman's (1986) required sample size for accuracy, in this case the minimum requirement of the size is 19. Therefore, to obtain accurate results, either regional level or river basin level that have sample size less than 19 sites are not calculated. For regional level, only Central Plain (70 sites), East (28 sites), and west (21 sites) regions have the sample size more than 19 sites and were analyzed by KDE (see detail in Table 3.3). For the river basin level, only Chao Phraya (34 sites) and Tha Chin (19 sites) have sample size equal or more than 19 sites and were also analyzed by KDE (see detail in Table 3.4). Due to small sample size, the Dharmacakra locations were only analyzed at national level.

Single KDEs were performed in CrimeStat 4.02 using Adaptive distance bandwidths and the Quartic probability function since it is one of the most commonly used in the analysis. Each sample data set was input into CrimeStat 4.02 one at a time. The output of KDE results was in the form of a polygon grid and was saved as shapefile format (Figure 3.12). The shapefiles were brought into ArcMap 10.3 where they could be displayed, analyzed, visually interpreted, and compared to each other (Figure 3.13). To generate the three-dimensional view of the results, the outputs from CrimeStat 4.02 were also saved as DAT format to create 3D surface in Surfer 10 (Figure 3.14).

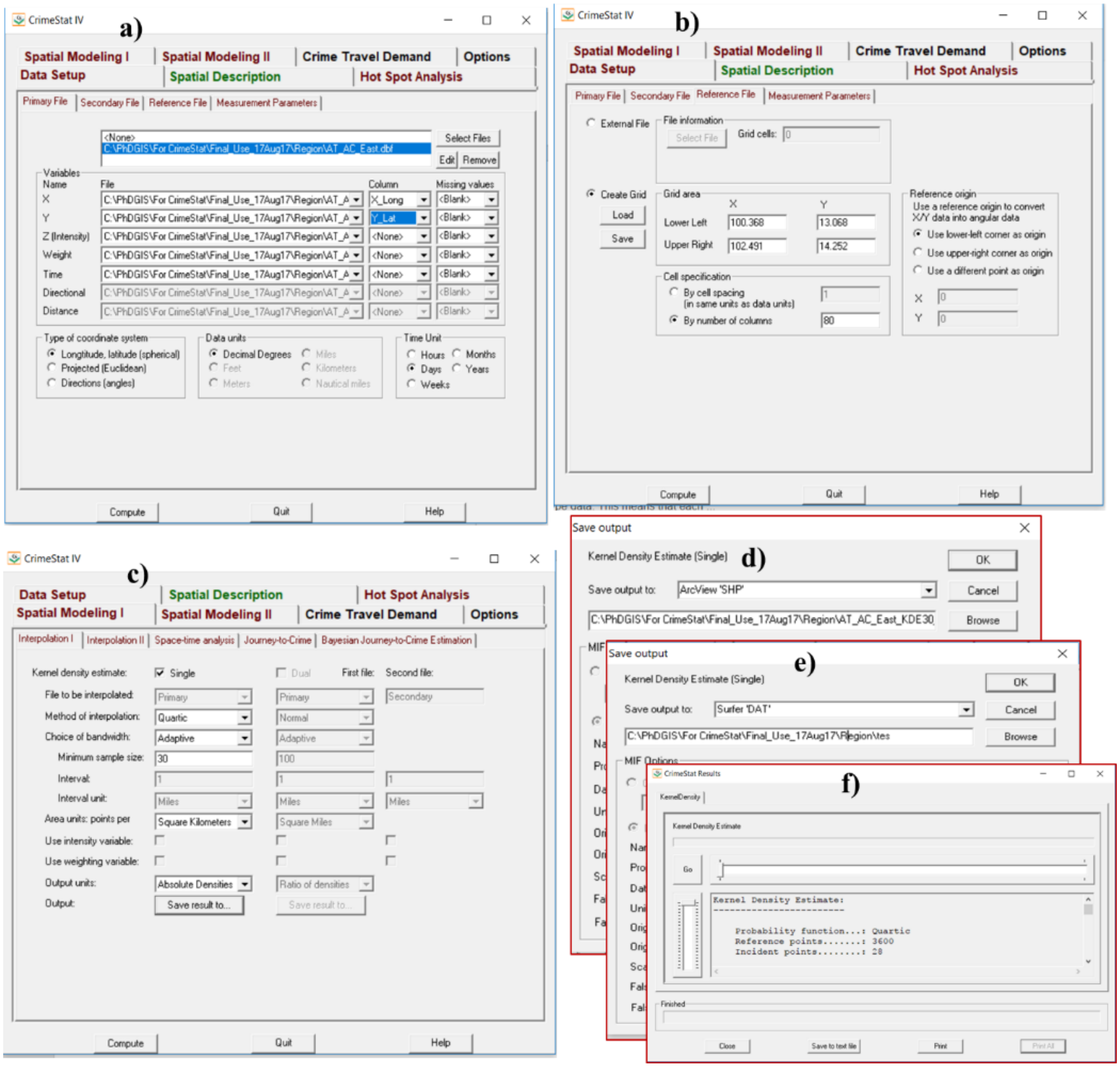


Figure 3.12: Perform single KDE analysis on the site data sets using CrimeStat 4.02; a) input site data set into CrimeStat, select X and Y coordinates to display data set, b) enter the X and Y coordinates that cover site data set and set cell specification, c) set up Method of interpolation =quartic, Choice of bandwidth = adaptive, Min. sample size = 30, d) save output to 'ArcView SHP' to be worked in ArcMap, e) save output to 'Surfer DAT' to be worked in Surfer, f) results

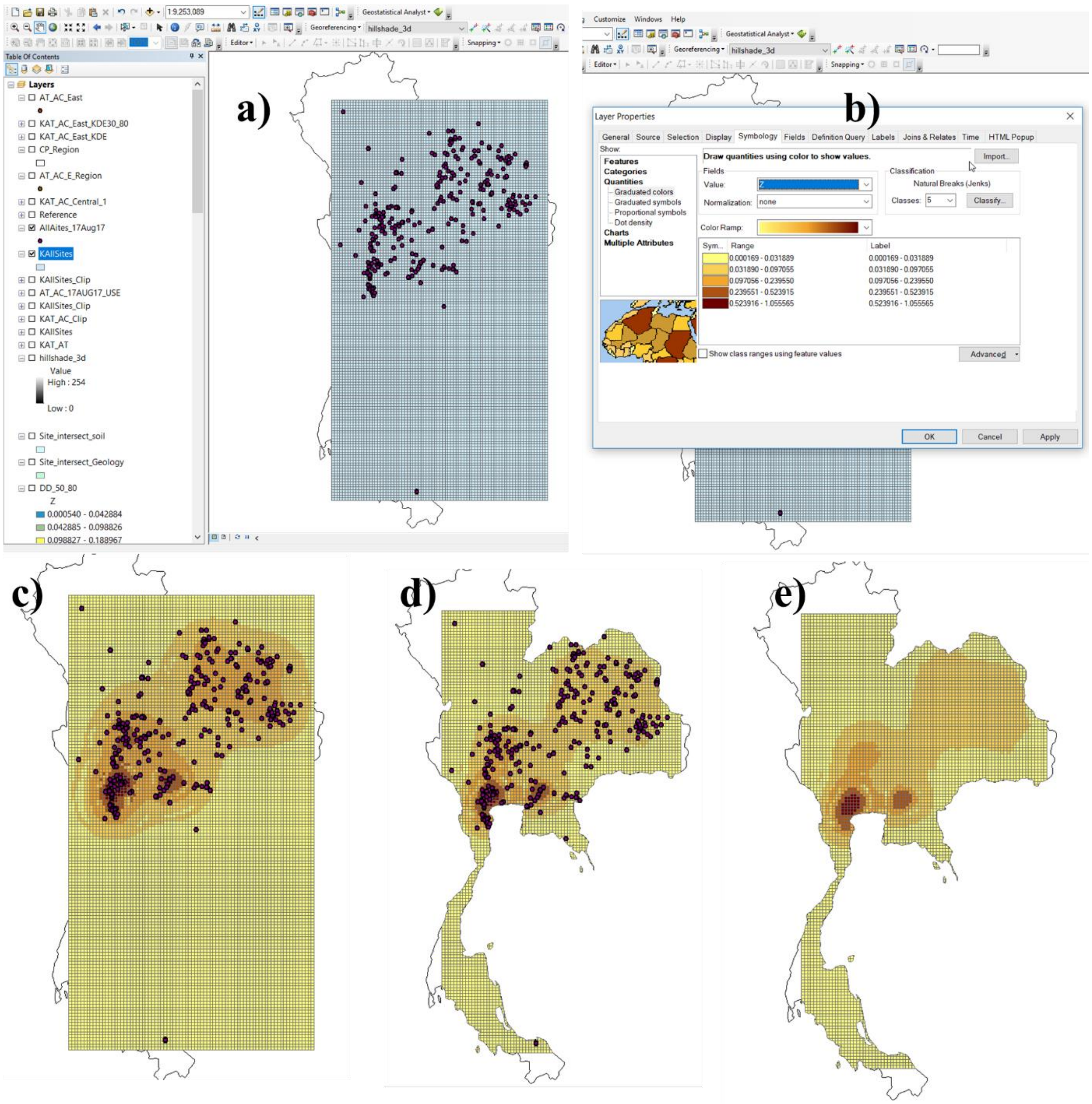


Figure 3.13: Creating choropleth maps in ArcMap used the results from CrimeStat: a) input shapefile result into ArcMap, b) set display z values with graduated colors to create a choropleth map, c) overlay with sites, d) clip result raster with Thailand boundary, e) result

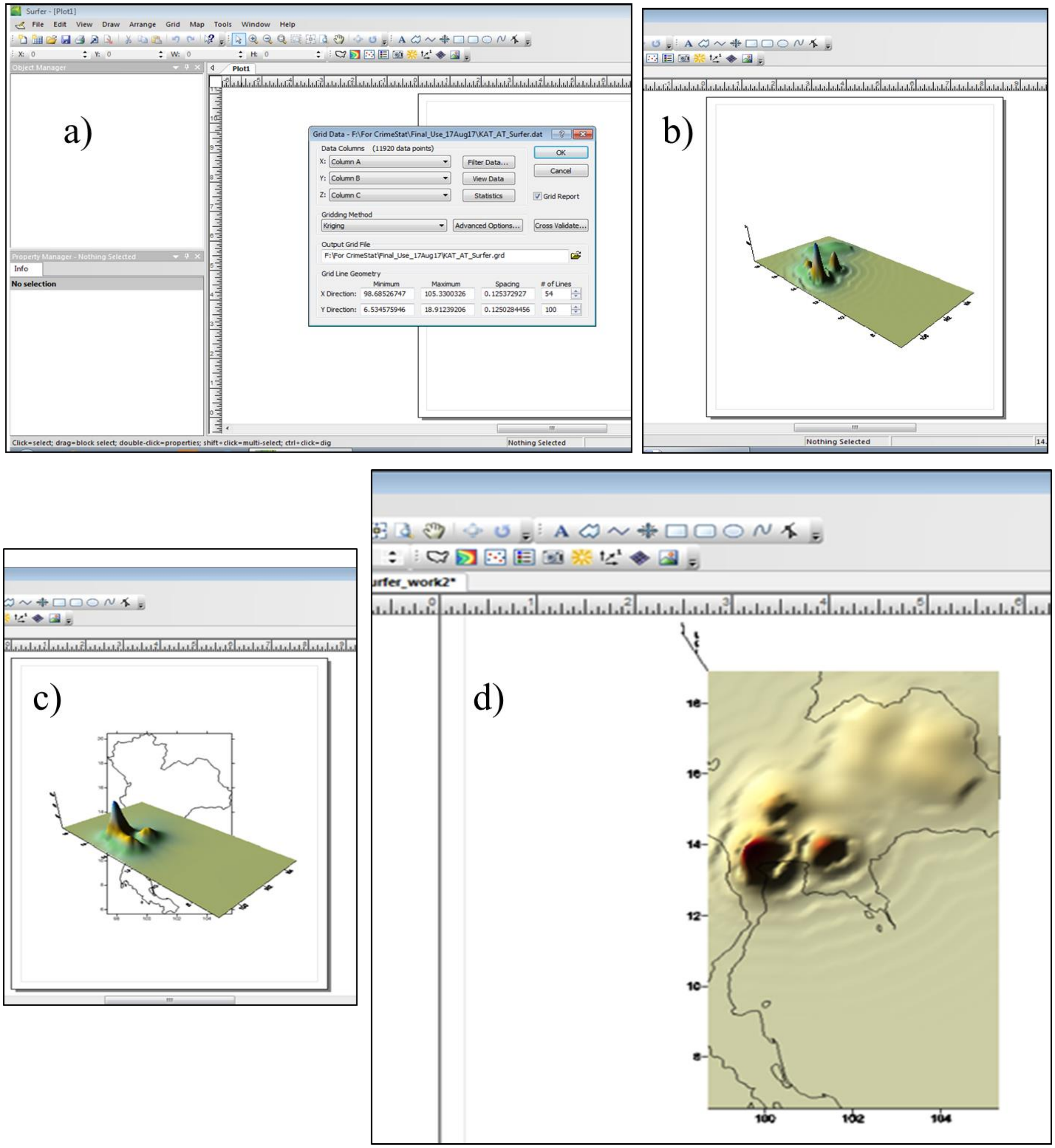


Figure 3.14: Creating 3D surface in Surfer used the results from CrimeStat: a) input DAT file result into Surfer, b) create 3D surface map, c) add basemap, d) overlay 3D surface with Basemap

3.3.4 Statistical Analysis

Several correlations are observed as shown in table 3.9. In order to assess the observed correlations, the variables are entered into Jmp Pro 13. In Jmp Pro 13, X (Factor) is the independent variable and Y (Response) is the dependent variable (Table 3.9). Jmp Pro 13 is used to create a graph, histogram, line graph, and a boxplot of these data. These descriptive statistic plots are graphical methods used to visually analyze the environment setting of Dvāravatī settlement. Chi-Square test in Jmp Pro 13 can be used to observe direct relationships and be used as a predictive model to predict data. In Jmp Pro 13, the Chi-Square analysis can be accessed in Analyze > Fit X by Y (Figure 3.15).

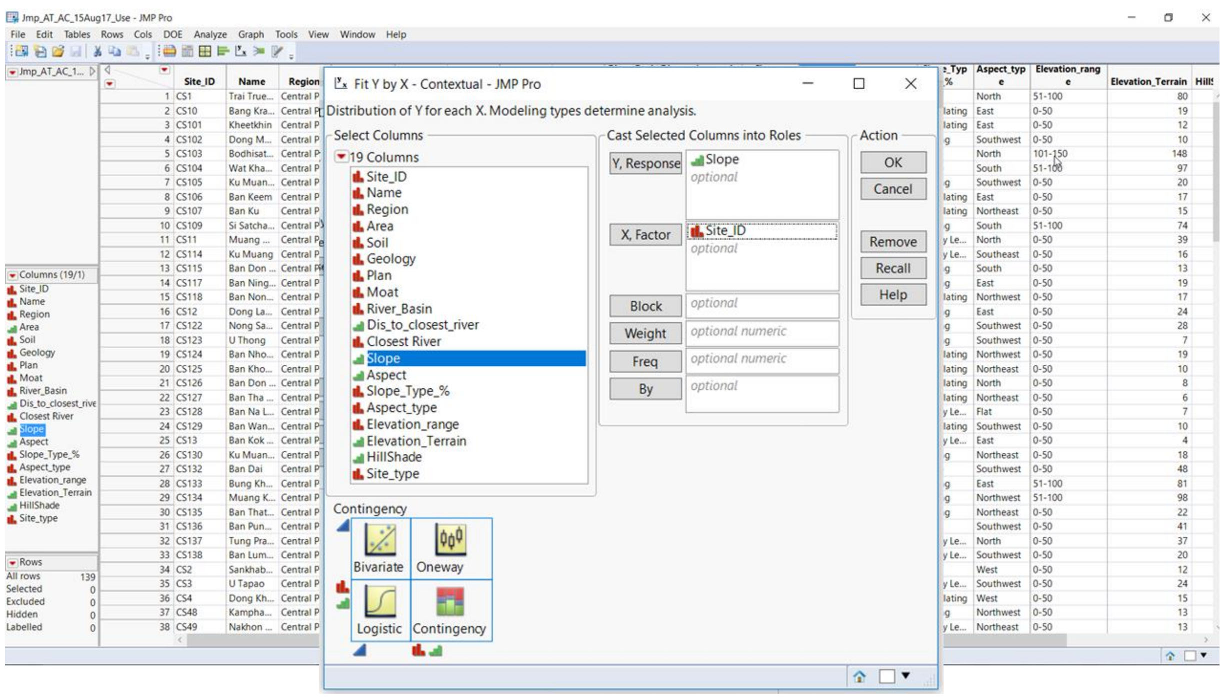


Figure 3.15: Statistical Analysis in Jmp Pro 13

The null hypothesis (H_0): There is no relationship between X and Y. The level of significance is set at 0.05. The results are shown in subsequent section.

Table 3.9: Variables used in statistical analyses

National Level		Regional Level		River Basin Level	
X (Factor)	**Y (Response)**	**X (Factor)**	**Y (Response)**	**X (Factor)**	**Y (Response)**
Site ID	Geology	Region	Geology	Basin	Geology
Site ID	Soil	Region	Soil	Basin	Soil
Site ID	Slope (%)	Region	Slope (%)	Basin	Slope (%)
Site ID	Aspect	Region	Aspect	Basin	Aspect
Site ID	Distance to closest river (m)	Region	Distance to closest river (m)	Basin	Distance to closest river (m)
Site ID	Plan	Region	Plan	Basin	Plan
Site ID	Size (SqKm)	Region	Size (SqKm)	Basin	Size (SqKm)
Site ID	Elevation (m)	Region	Elevation (m)	Basin	Elevation (m)

3.3.5 Rank-Size Analysis

In this study, rank-size analysis is used primarily to measure the overall Dvāravatī settlement system and in the formulation and examination of probable settlement hierarchy that existed in Thailand. Owing to the presently available data, only 59 moated sites were used to perform rank-size analysis (Table 3.10). To analyze a rank-size distribution, these 59 sites are descendingly ranked and settlement size is plotted against settlement rank in that descending array of sizes. The settlement rank and settlement size were plotted as a line of the logarithms. In addition, 13 moated sites that hold Dharmacakras are also perform rank-size analysis. The results are present in chapter 4.

Table 3.10: Settlement rank-size distributions in ascending order

Rank	Size in SqKm	Site ID	Rank	Size in SqKm	Site ID	Rank	Size in SqKm	Site ID
1	6.594	CS49	21	0.83	CS102	41	0.34	ES14
2	4.692	CS74	22	0.8	CS107	42	0.275	CS4
3	4.05	NES50	23	0.785	CS86	43	0.265	CS12
4	3.953	NES31	24	0.701	CS56	44	0.251	CS101
5	3.15	CS2	25	0.613	CS91	45	0.189	CS59
6	3.14	NES661	26	0.605	CS57	46	0.172	CS114
7	3.11	NES47	27	0.547	CS3	47	0.16	CS85
8	1.952	NES48	28	0.536	CS60	48	0.145	CS10
9	1.9	NES51	29	0.53	ES31	49	0.134	CS134
10	1.71	WS50	30	0.525	CS48	50	0.119	CS130
11	1.623	NES41	31	0.5	CS122	51	0.1156	CS129
12	1.61	WS23	32	0.5	ES43	52	0.102	CS54
13	1.546	NES1	33	0.465	CS105	53	0.1	CS106
14	1.292	CS98	34	0.45	CS63	54	0.1	NES29
15	1.226	CS133	35	0.438	CS55	55	0.08	CS11
16	1.12	ES37	36	0.43	CS94	56	0.0625	CS6
17	0.98	ES28	37	0.415	ES2	57	0.04	CS58
18	0.963	CS123	38	0.396	CS137	58	0.02	CS53
19	0.934	ES7	39	0.39	CS89	59	0.01	CS62
20	0.84	CS132	40	0.375	NES53			

CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this chapter is to discuss the results of settlement pattern analysis. Using Nearest Neighbor Analysis (NNA), Kernel Density Estimation (KDE), rank–size analysis, and statistical analyses, it is possible to exam the spatial pattern of Dvāravatī settlement, Dharmacakra locations, and their relationships. This chapter addresses environment setting, spatial distributions of Dvāravatī settlements and Dharmacakras, rank-size distribution, relationship between Dharmacakra locations and Dvāravatī settlements, and relationship between Dharmacakra locations and their motifs. The results are presented using GIS analysis, maps, statistical tables, graphs, and histograms. However, the main challenge is the fact that there is limit on precise location of sites hence the results using several methods and softwares are strenuous to achieve. The subsequent sections in this chapter present the results and the discussion.

4.1 Environmental Setting of Dvāravatī Settlements

4.1.1 Relationship between Spatial Variables and Sites

Dvāravatī settlement system can be analyzed by considering the relationships that existed between settlements in each three different geographic levels and the sets of quantified environmental variables. It is initially assumed that the sites within the same region and river basin are functionally similar. Therefore, the sets of quantified environmental variables between each of region and river basin are expected to be reflected differently.

To reconstruct the ancient environmental setting of Dvāravatī settlement, only 139 sites of total 425 sites (only Ancient Town and Ancient Community Types) were used (Figure 4.1). The environmental variables used, which are considered important factors of site locations are: 1) the soil type; 2) the geology type; 3) slope; 4) aspect; 5) elevation; and 6) the distance to the closest water source. It should be noted that the variables used in this study are based on presently available data. The result may be altered in the further future research when there are more precise data applied, for example, the precise locations of sites, site size, number of moats, higher resolution DEM, paleogeographic and paleoclimatic data, accurately localized soil and geology data, or future excavation data.

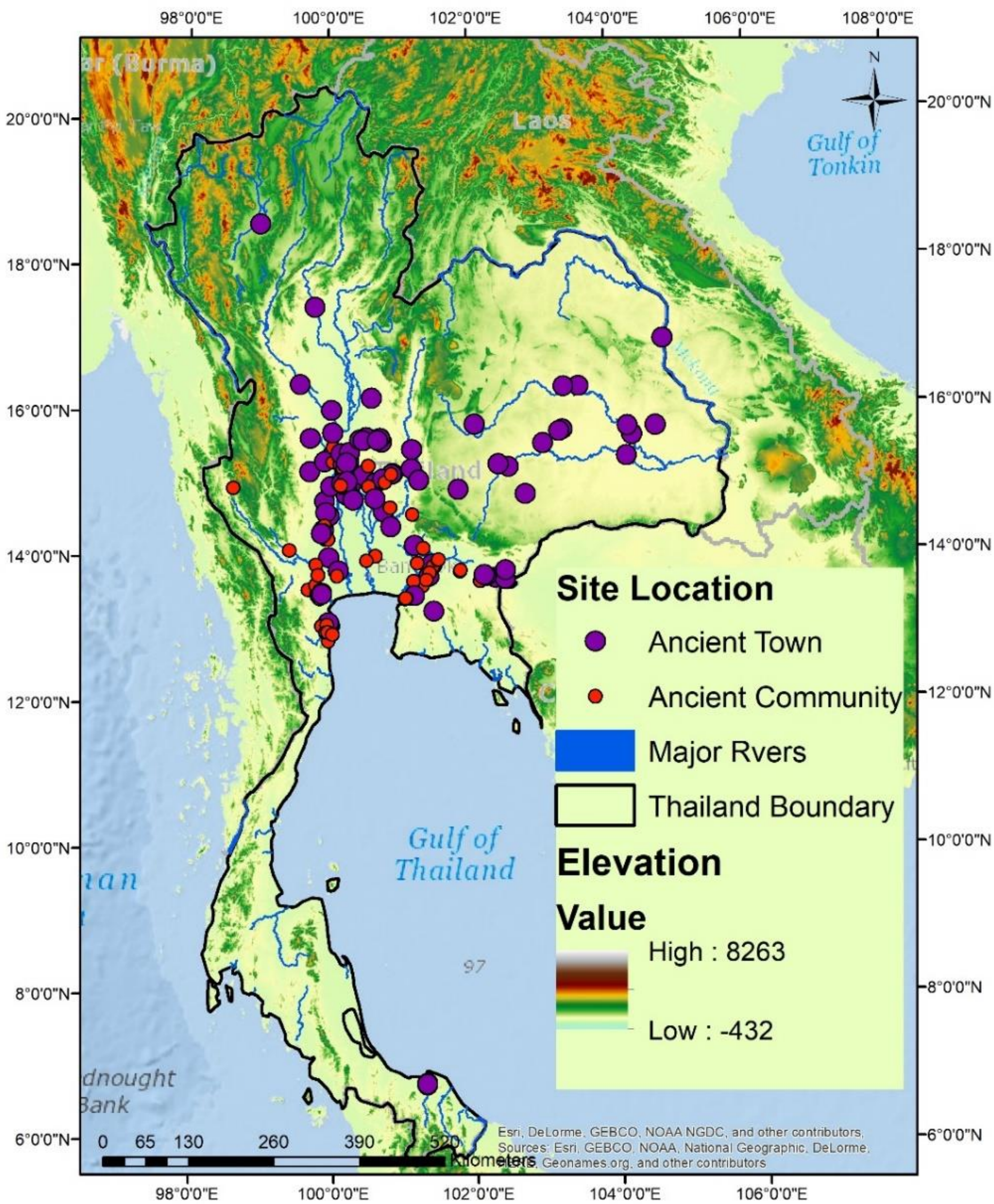


Figure 4.1: 139 site locations: 83 Ancient Towns and 56 Ancient Communities, map by Areerut Patnukao, basemap from Esri and other contributors

In the regional level, 70 sites (50%) are located in the Central Plain. In river basin level, Chao Phraya basin in Central Plain contains the highest number of sites, 34 sites (24.5%) (Figure 4.2). Overall, there are 64 sites (46%) situated in Gleyic Acrisols (Ag) soil type, and 26 sites (19%) situated in Alluvial deposits (Figure 4.3).

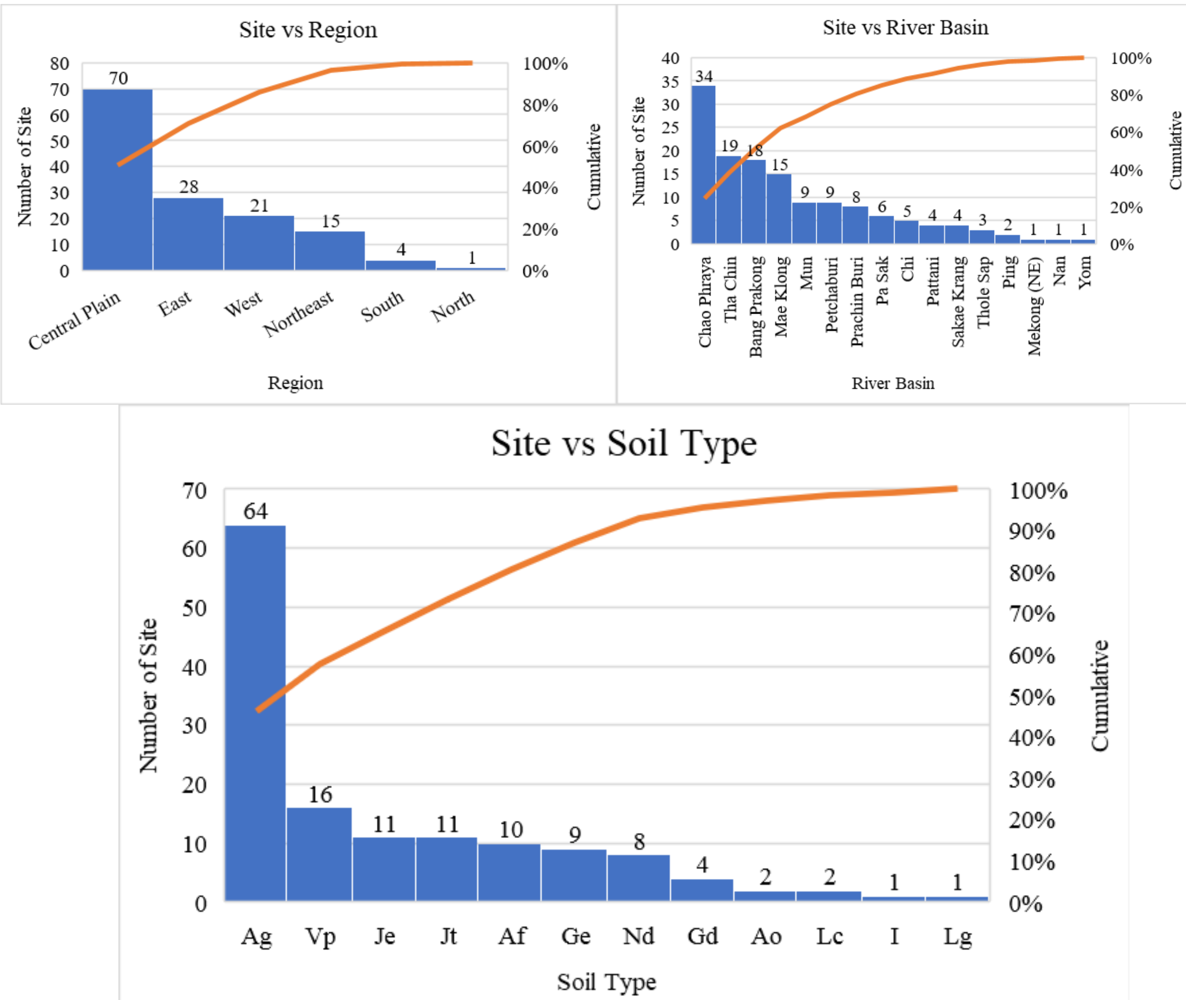


Figure 4.2: Graphs show the frequency of site found in each region (Left), river basin (Right), and soil type (Bottom) in descending order, with a cumulative (%) of the total

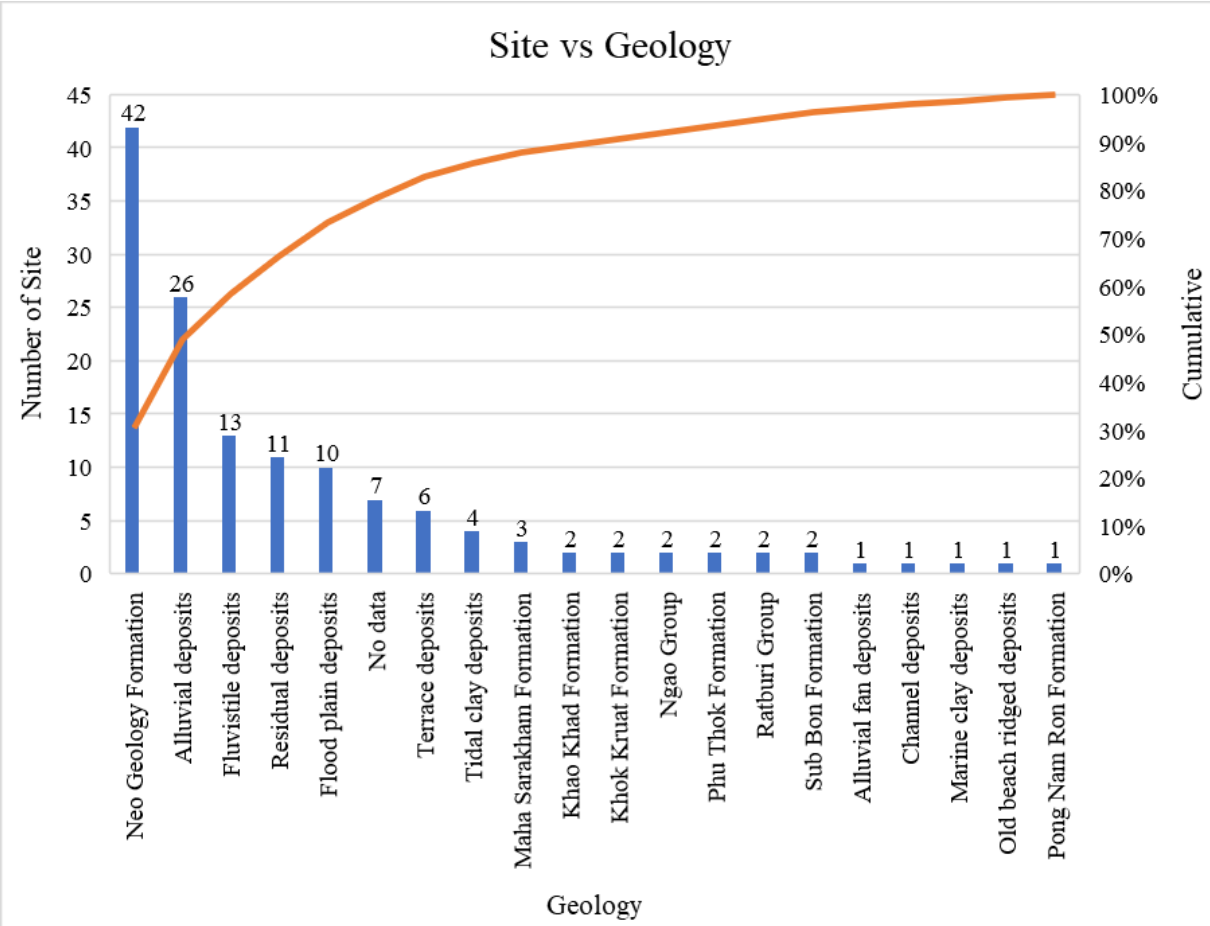


Figure 4.3: Graphs show the frequency of site found in geology type in descending order, with a cumulative (%) of the total

Most of the sites are located in southwest (18.7%) and northeast (16.5%) directions of the downhill slope faces. The majority of the sites are situated in undulating (39.6%) and rolling (31.7%) slopes. Sites in Chao Phraya and Mae Klong basins are located in all slope type. 70% of sites are located in elevation below 50 m MSL. The proximity distances to access water source are within 5 km (24.46%), 10 km (24.46%), and 1 km (22.3%) respectively. All sites are located within 30 km from water source (Figure 4.4).

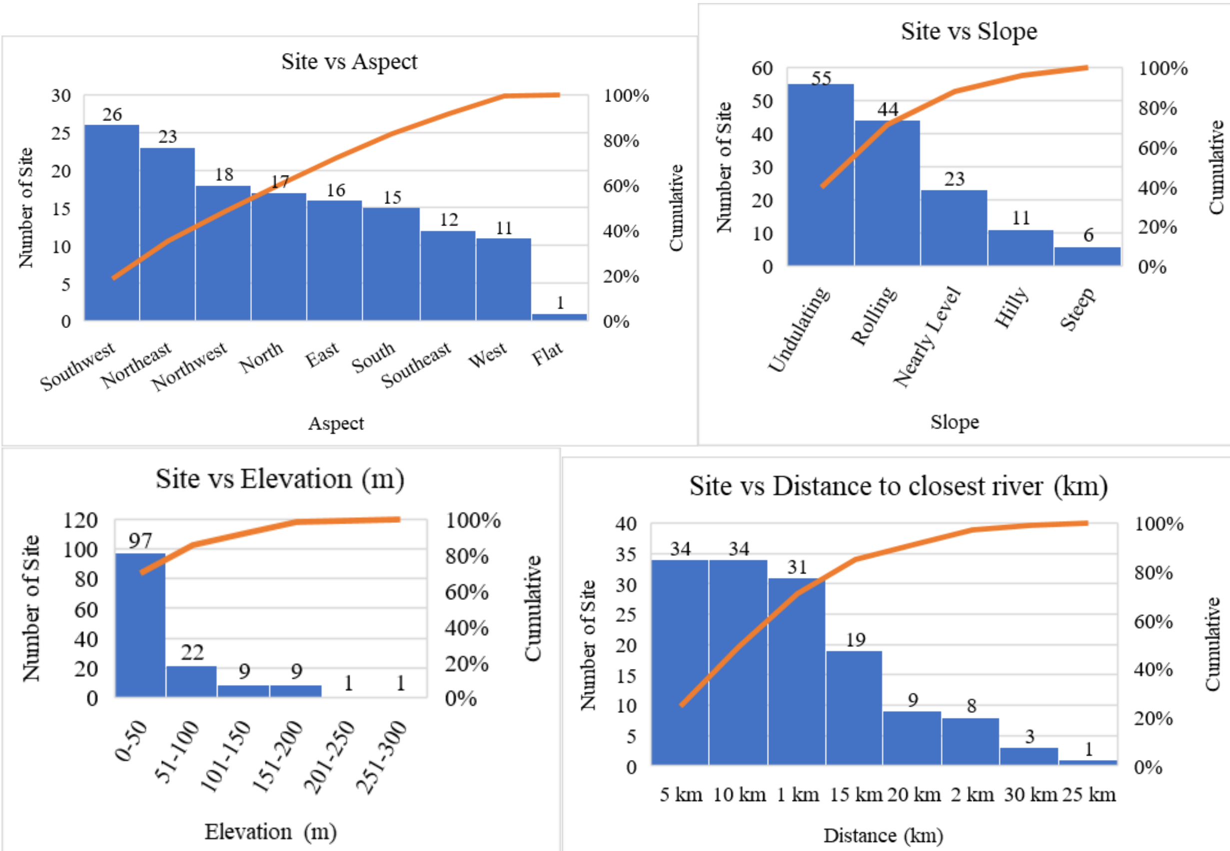


Figure 4.4: Graphs show the frequency of site located in each aspect (Upper Left), slope (Upper Right), elevation (Lower Left), and distance to the closest river (km) (Lower Right) in descending order, with a cumulative (%) of the total

A Chi-Square test measures the degree of relationship of the data whether there is a real relationship or randomly happens. The p-value obtained through the Chi-Squared test shows if the pattern is statistically significant (p = 0.05 or less). By Chi-Square test, the relationships between sites and spatial variables are revealed and presented below.

National Level

The results from Chi-Square test failed to reject the null hypothesis since their p-values are greater than 0.05. There is no significant relationship between X and Y variables in national level (Table 4.1). In another word, there is no significant relationship between individual site and spatial variables at the national level.

Table 4.1: The results from statistical analysis between sites and different spatial variables in national level

National Level		The Results			
X (Factor)	**Y (Response)**	**N**	**DF**	**χ^2**	**Prob> χ^2**
Site ID	Geology	139	2622	2641	0.3932
Site ID	Soil	139	1518	1529	0.4163
Site ID	Slope	139	552	556	0.4443
Site ID	Aspect	139	1104	1112	0.427
Site ID	Distance to closest river (m)	139	966	973	0.4309
Site ID	Plan	139	2070	2085	0.404
Site ID	Size	59	3248	3304	0.2422
Site ID	Elevation	139	690	695	0.4395

Regional Level

The results show significant relationships between sites and other spatial variables, including geology types, soil types, distance to the closest river, and elevation in regional level which reject the null hypothesis because their p-values are less than 0.05 (Table 4.2). While there are no significant relationships between sites and other variables since their p-values are greater than 0.05, these relationships failed to reject the null hypothesis (see detail in Appendix E Table E.1a-d).

Table 4.2: The results from statistical analysis between sites and different spatial variables in regional level

Regional Level		The Results			
X (Factor)	**Y (Response)**	**N**	**DF**	**χ^2**	**Prob> χ^2**
Region	Geology	139	2	26.203	***<.0001***
Region	Soil	139	3	21.489	***<.0001***
Region	Slope	139	2	2.997	0.2235
Region	Aspect	139	8	9.448	0.3059
Region	Distance to closest river (m)	139	4	16.241	***0.0027***
Region	Plan	64	13	17.627	0.1722
Region	Size	59	56	54.42	0.5349
Region	Elevation	139	1	4.414	***0.0357***

Overall, 30% of sites are located in Neo Geology Formation. Almost 19% of sites are located in Alluvial deposits. These deposits are found in the biggest number in Central Plain, East, North, and Northeast regions (Figures 4.5 and 4.6) (see detail in Appendix E Table E.1a).

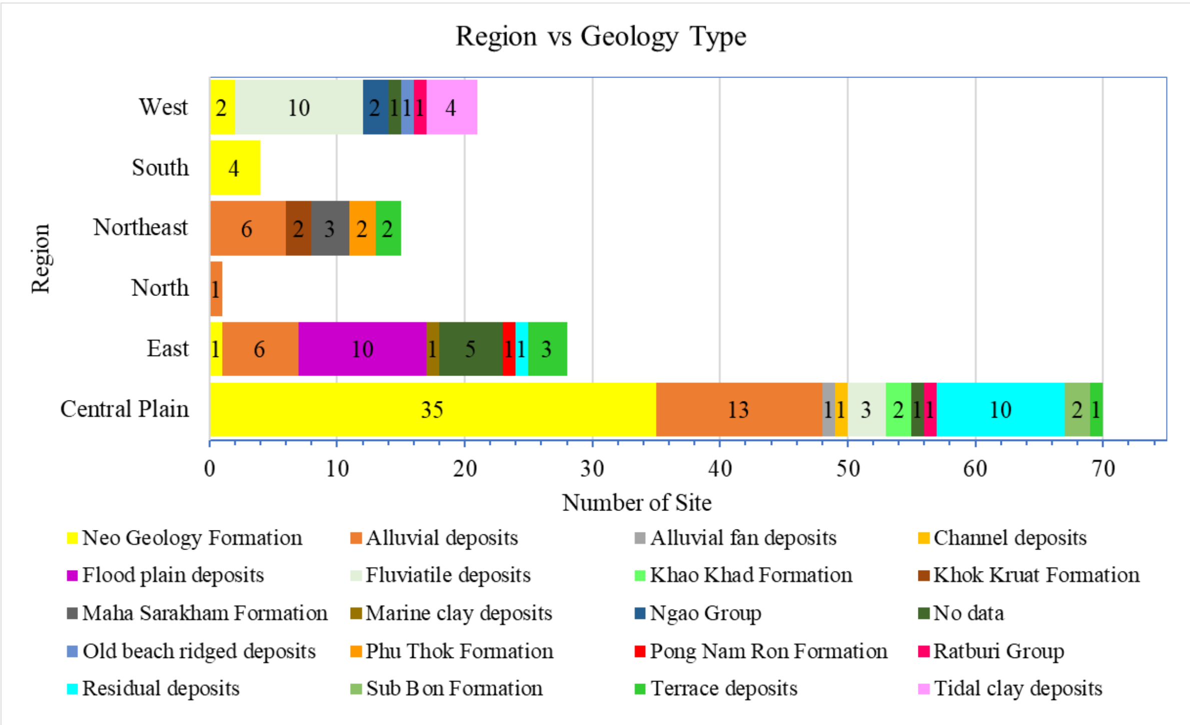


Figure 4.5: A histogram shows number of sites by geology types in each region

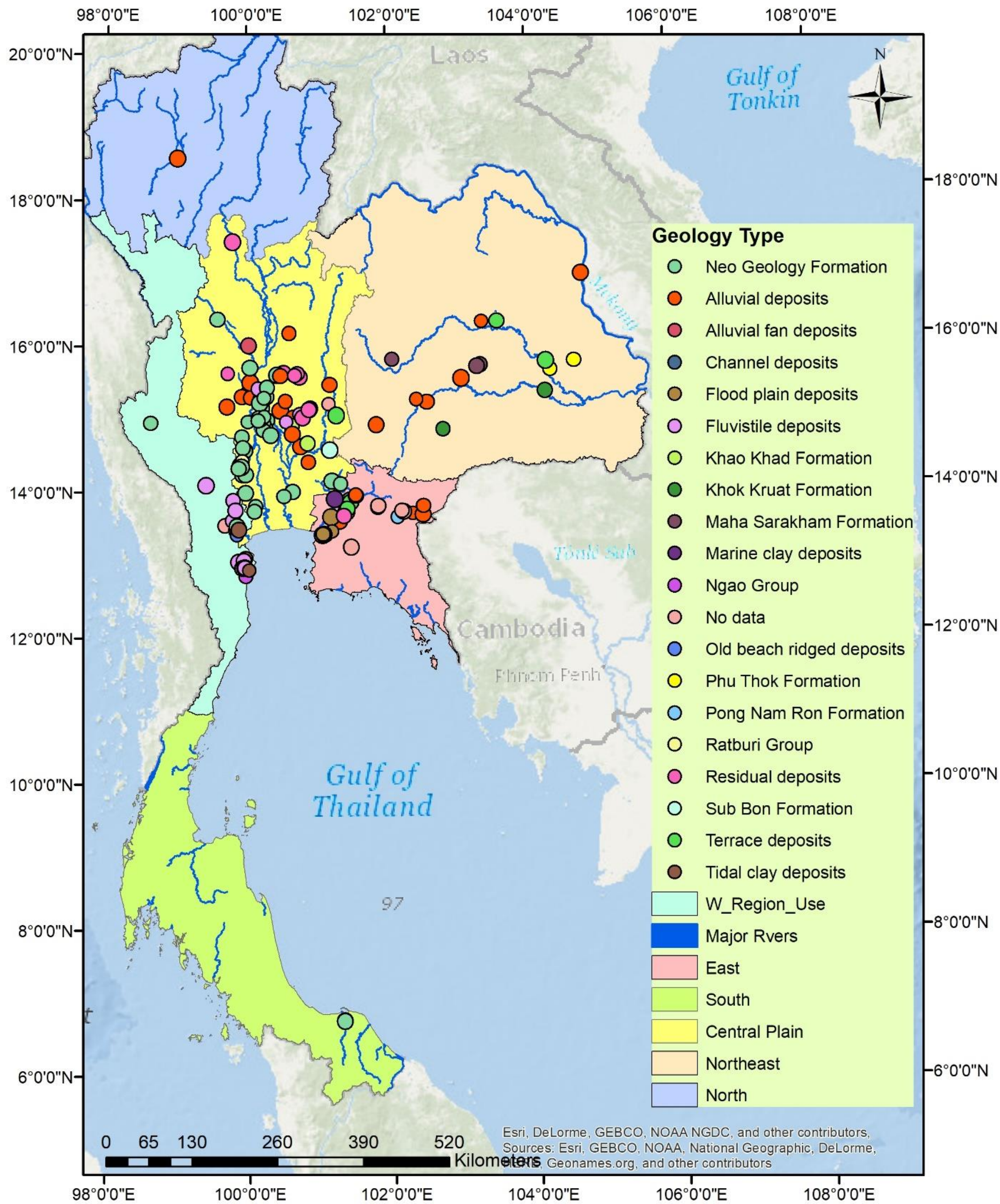
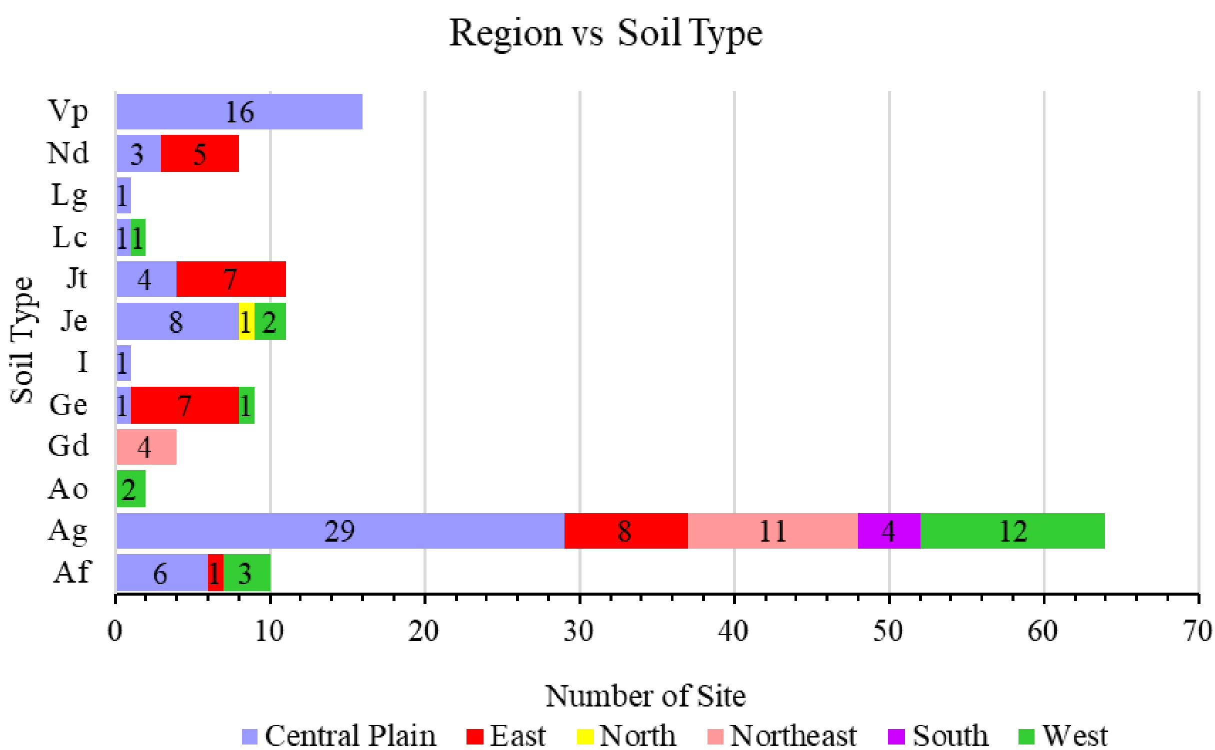


Figure 4.6: The distribution of site locations by geology types in relation to region, map by Areerut Patnukao, basemap from Esri and other contributors

The majority of sites (41%) are located in Gleyic Acrisols (Ag) which are suitable for growing rice. This may indicate that Dvāravatī sites are located to take advantage of the rice growing potential of soils. The Central Plain has the highest number of sites, 71 sites (51%). The sites in this region are distributed across almost all soil types (Figures 4.7 and 4.8) (see detail in Appendix E Table E.1b).



Af = Ferric Acrisols, Ag= Gleyic Acrisols, Ao= Orthic Acrisols, Gd= Dystric Gleysols, Ge= Eutric Gleysols, I= Lithosols, Je= Eutric Fluvisols, Jt= Thionic Fluvisols, Lc=Chromic Luvisols, Lg=Gleyic Luvisols, Nd= Dystric Nitosols, Vp=Pellic Vertisols

Figure 4.7: A histogram shows number of sites by soil types in each region

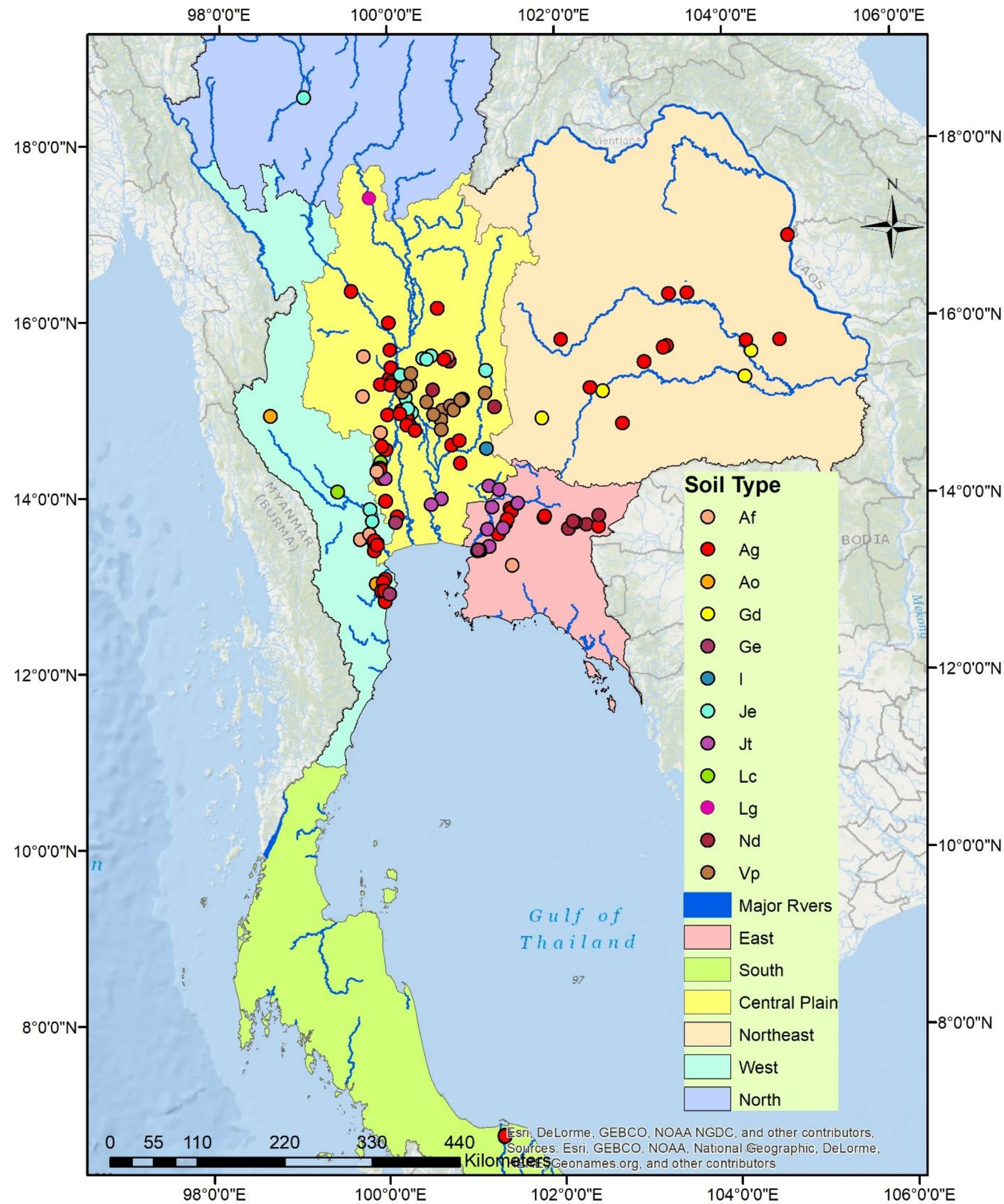


Figure 4.8: The distribution of site locations by soil types in relation to region, map by Areerut Patnukao, basemap from Esri and other contributors

There are 31 sites (22%) that can be accessed to water resource within 1 km (Figures 4.9, 4.10a, and 4.10b) (see detail in Appendix E Table E.1c). The Central Plain has the most variety distances to access water resource which correspond to the highest in number of sites found (Figure 4.10c). All sites are located within 15 km to water source in Eastern region (Figure 4.10d). All sites in Northeastern region are located within 20 km of the river source (Figure 4.11a). So far, only one site in Northern region belongs to Dvāravatī period and located within 1 km to closest river (Figure 4.11b). All sites in Southern region are located within 5 km of the Pattani river (Figure 4.11c). In Western region, all sites are located within 10 km of the river source (Figure 4.11d).

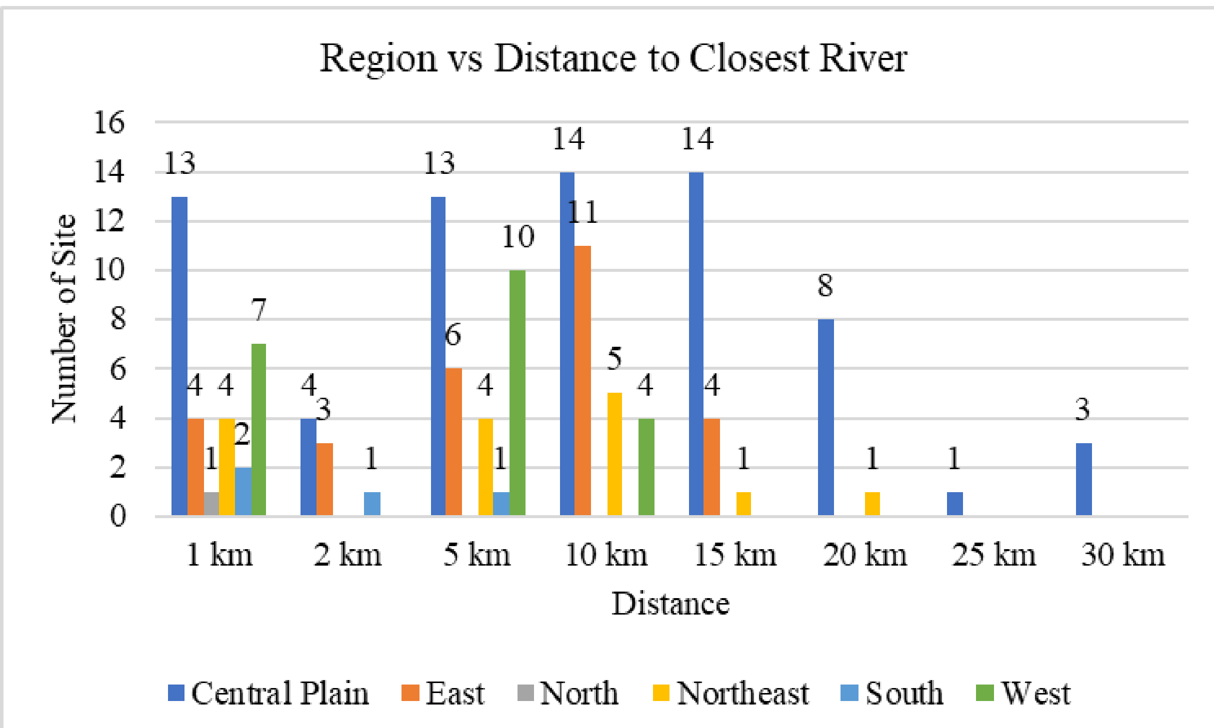


Figure 4.9: A histogram shows number of sites by distance to the closest river in each region

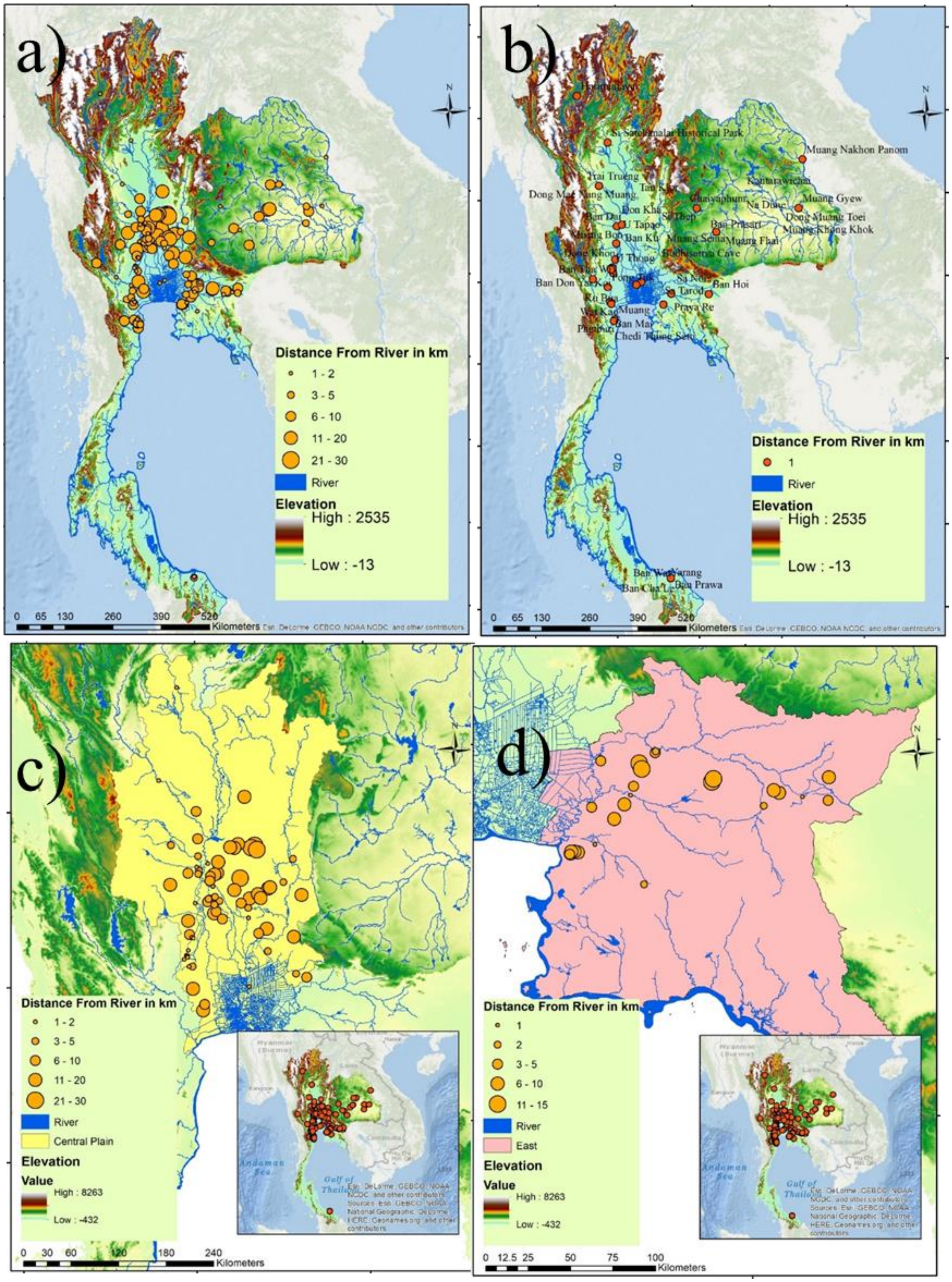


Figure 4.10: The distribution of sites to the closest water source: a) all sites; b) only sites within1 km to water source throughout country; c) within 30 km to water source in Central Plain; d) within 15 km to water source in East, map by Areerut Patnukao, basemap from Esri and other contributors

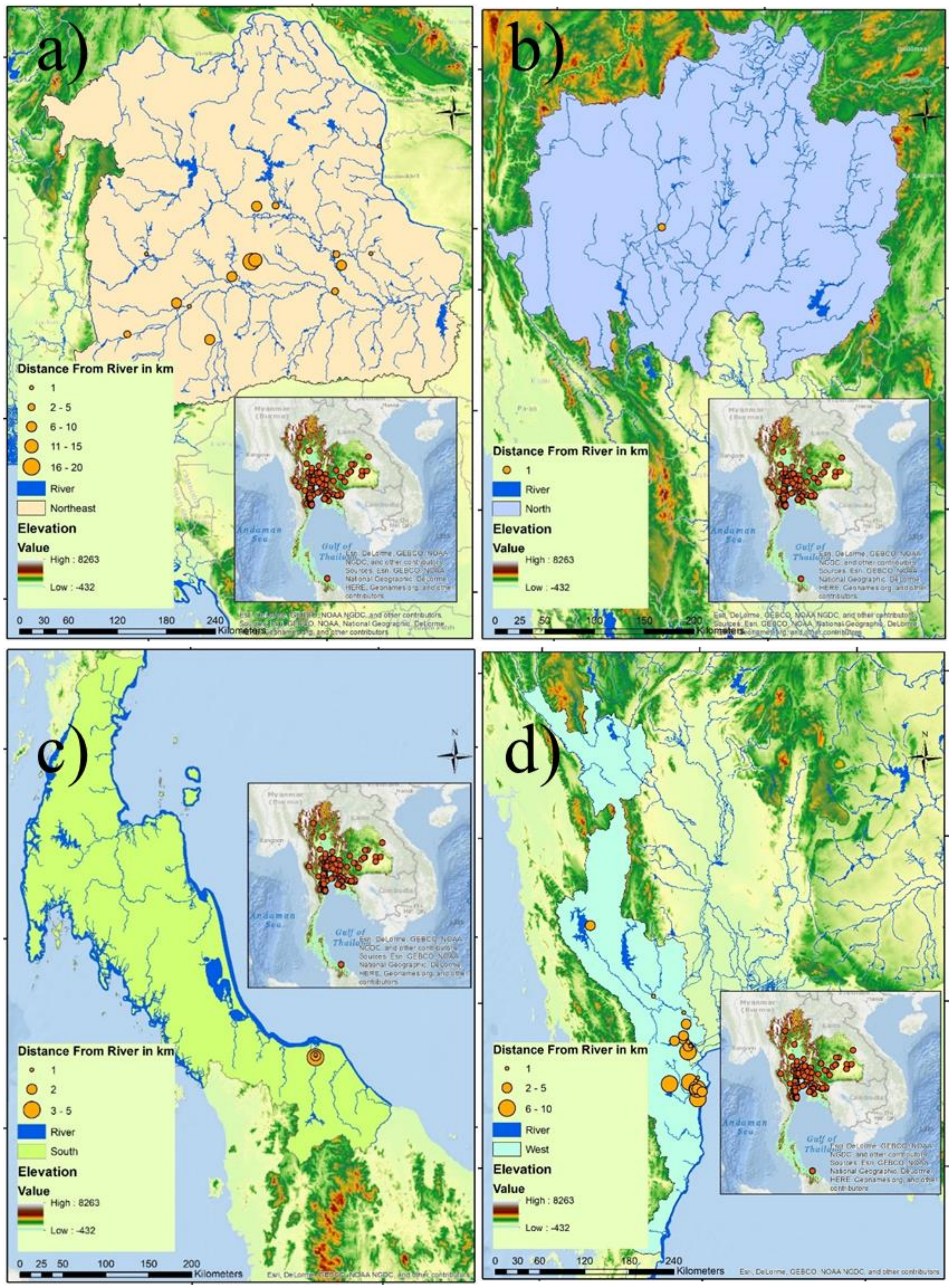


Figure 4.11: The distribution of sites to the closest water source: a) within 20 km to water source in Northeast; b) within 1 km to water source in North; c) within 5 km to water source in South; d) within 10 km to water source in West, map by Areerut Patnukao, basemap from Esri and other contributors

70% of the sites are located below 50 m above MSL. Central Plain has 52 out of 71 sites (73%) located in low elevation which corresponds to its geographic setting (Figures 4.12 and 4.13) (see detail in Appendix E Table E.1d).

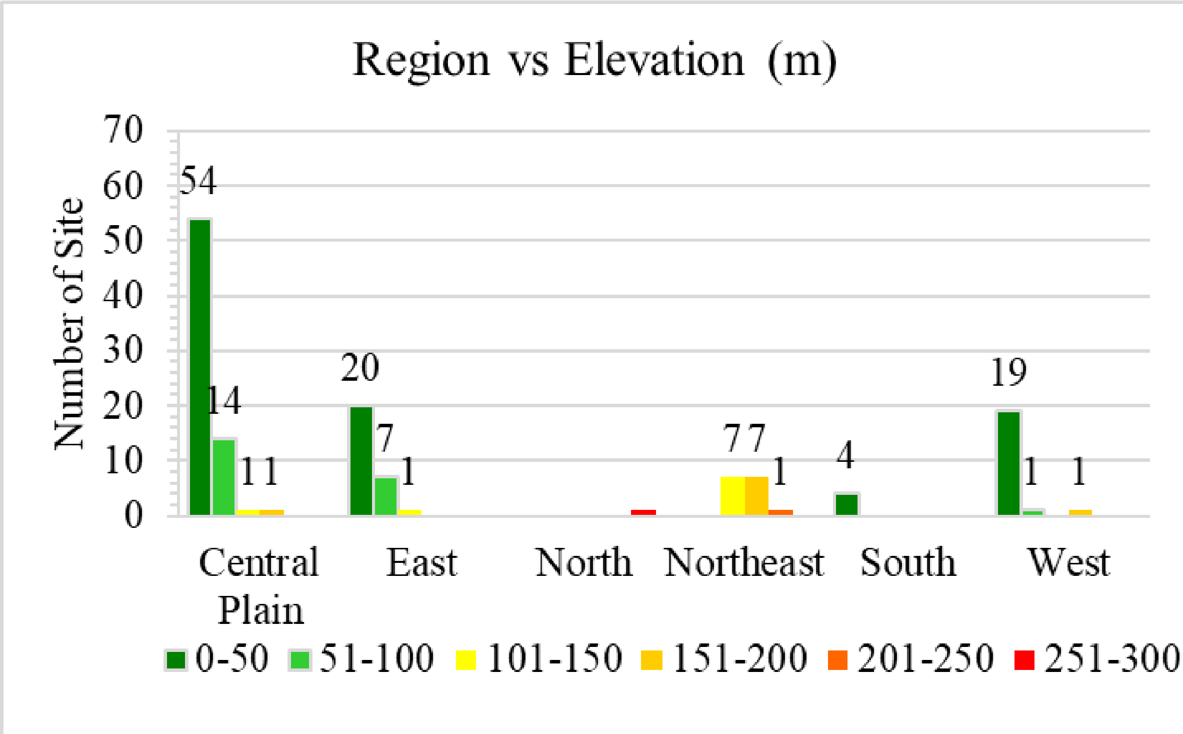


Figure 4.12: A histogram shows number of sites by elevation in each region

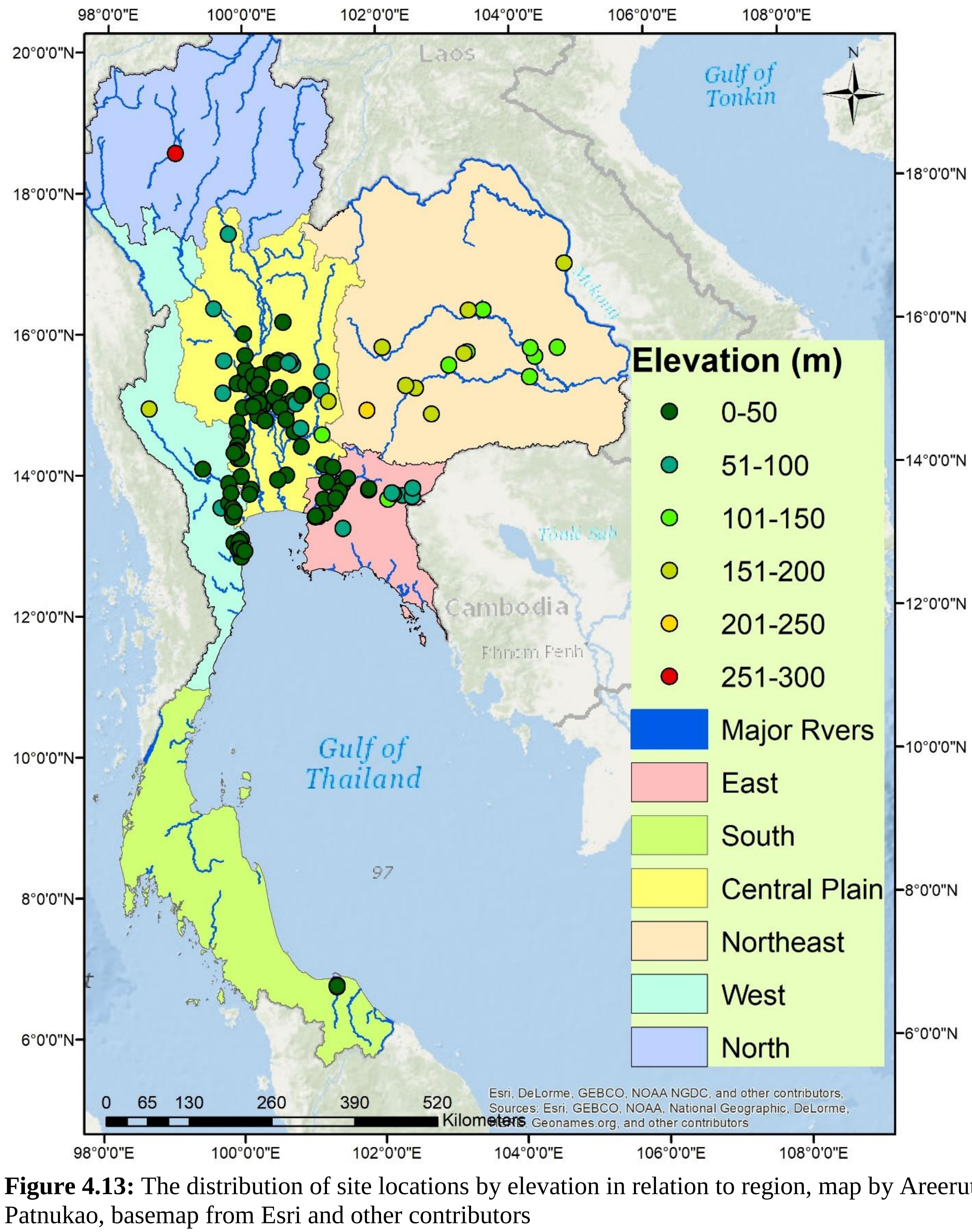


Figure 4.13: The distribution of site locations by elevation in relation to region, map by Areerut Patnukao, basemap from Esri and other contributors

River Basin Level

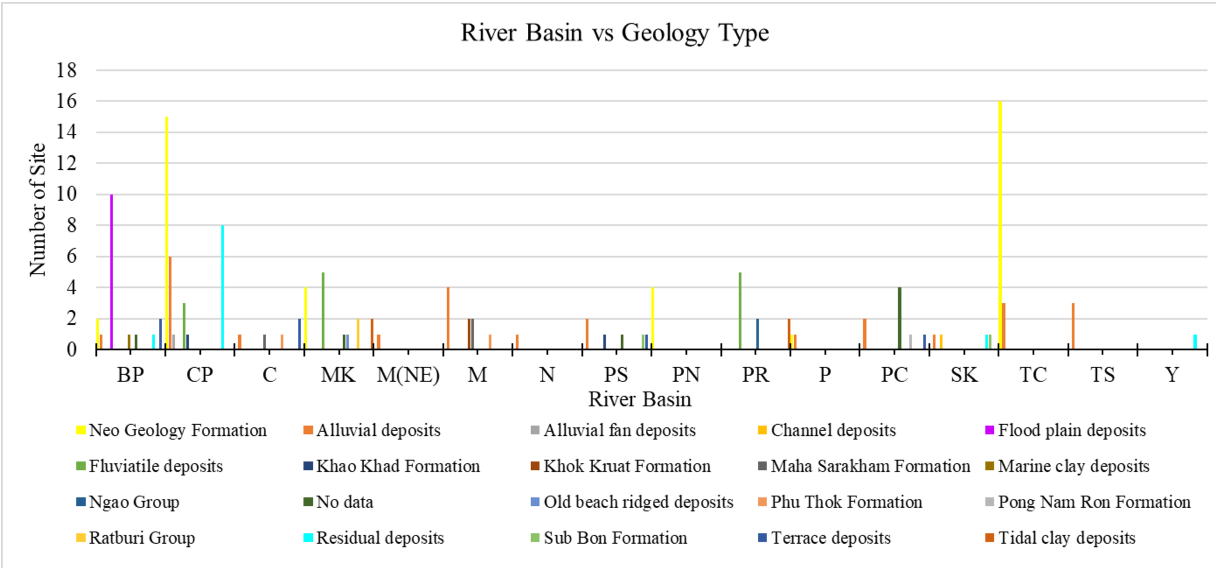
The results show the significant relationships between sites and other spatial variables, including geology types and elevation in river basin level which reject the null hypothesis because their p-values are less than 0.05 (Table 4.3). Certain geologies and elevations are significantly associated with sites in the same river basin. Even though the p-values of the relationships between sites and spatial variables, including soil types, slope, and distance to the closest river are less than 0.05, it is not adequate to conclude that there are significant relationships since expected values are less than 5. The Chi-Square test is highly sensitive to small sample size and small frequencies in the cells of tables. There are no significant relationships between sites and other variables since their p-values are greater than 0.05, these relationships failed to reject the null hypothesis (see detail in Appendix E Table E.2a-d).

Table 4.3: The results from statistical analysis between sites and different spatial variables in river basin level

River Basin Level		**The Results**			
X (Factor)	**Y (Response)**	**N**	**DF**	**χ^2**	**Prob> χ^2**
Basin	Geology	139	8	47.569	***<0.0001***
Basin	Soil	139	12	78.76	<0.0001*
Basin	Slope	139	8	20.226	0.0095*
Basin	Aspect	139	32	26.886	0.7232
Basin	Distance to closest river(m)	139	16	34.442	0.0047*
Basin	Plan	64	52	56.816	0.3004
Basin	Size	59	224	228.543	0.4034
Basin	Elevation	139	4	35.931	***<0.0001***

* = Warning: 20% of cells have expected count less than 5, Chi-Square suspect

Almost 19% of sites are located in Alluvial deposits. Alluvial deposits are found in almost every river basin except Mae Klong and Pattani river basins. The sites within Chao Phraya river basin have the highest number of geology types, 6 types. Among these types, Flood plain deposits have the greatest number of sites, 10 sites (Figures 4.14 and 4.15) (see detail in Appendix E Table E.2a).



BP = Bang Prakong, CP= Chao Phraya, C= Chi, MK= Mae Klong, M (NE) = Mekong (Northeast), M= Mun, N= Nan, PS= Pa Sak, PN= Pattani, PR= Phetchaburi, P= Ping, PC= Prachin Buri, SK= Sakae Krang, TC= Tha Chin, TS= Thole Sap, Y= Yom

Figure 4.14: A histogram shows number of sites by geology types in each river basin

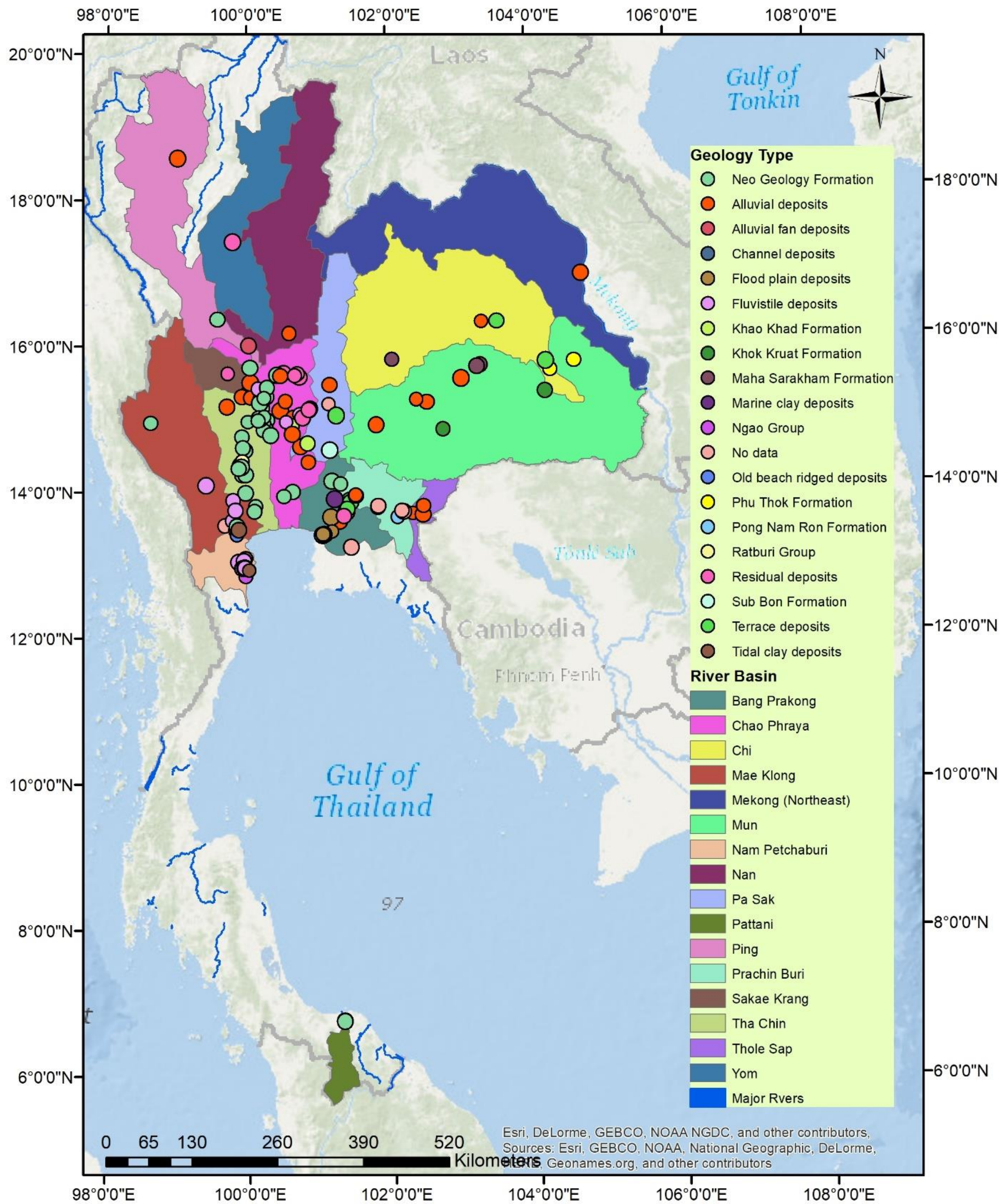


Figure 4.15: The distribution of site locations by geology types in relation to river basin, map by Areerut Patnukao, basemap from Esri and other contributors

Most of the sites in almost river basins, except Chi, Mun, and Mekong, are located in elevation below 50 m MSL (Figures 4.16 and 4.17) (see detail in Appendix E Table E.2b).

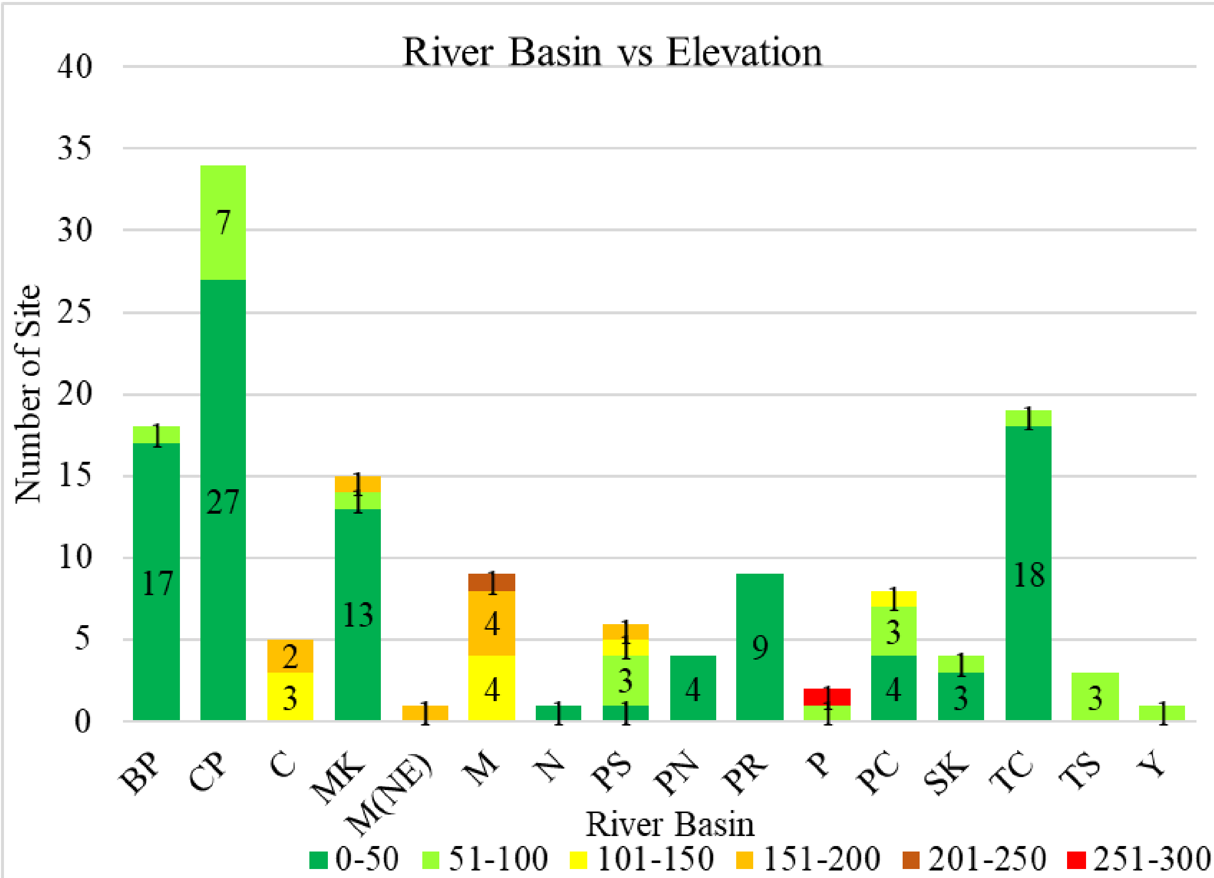


Figure 4.16: Histograms show number of sites by elevation in each river basin

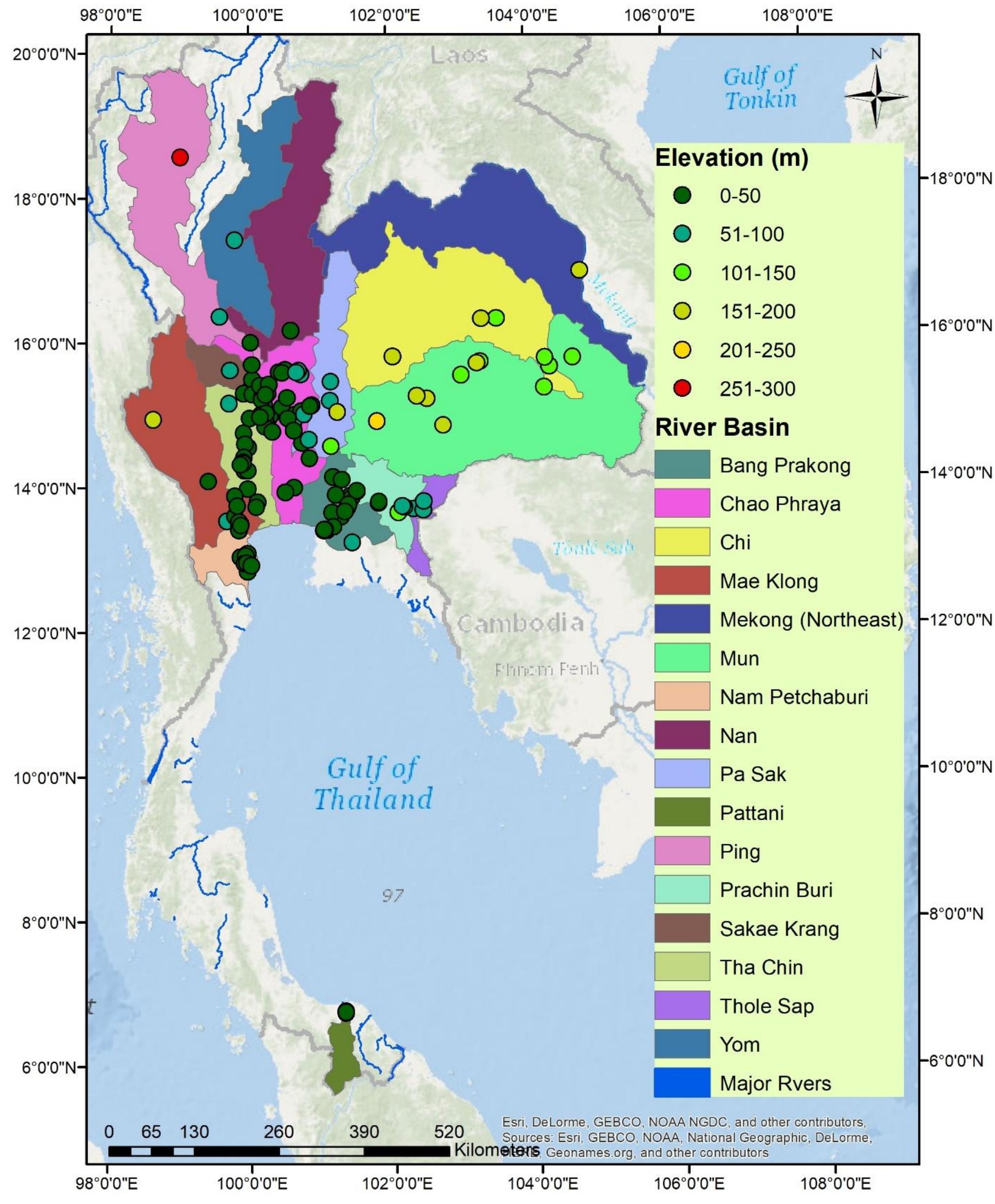


Figure 4.17: The distribution of site locations by elevation in relation to river basin, map by Areerut Patnukao, basemap from Esri and other contributors

4.1.2 Potential Stone Workshop Sources

By overlaying stone workshop sites with geology layer, reveals the pattern and spatial distribution of additional potential stone sources (Table 4.4 and Figure 4.18).

Table 4.4: The cutting stone sources in Northeast region and stone workshop in Western region

Site_ID	Region	Name__English	District	Province	Rock Unit	Symbol
NES18	Northeast	Phu Khok MA	Waeng Yai	Khon Kaen	Phu Phan Formation	Kpp
NES30	Northeast	Sikew Stone Cutting Site	Sikhio	Nakhon Ratchasima	Phu Phan Formation	Kpp
NES668	Northeast	Phu Papueng	Tao Ngoi	Sakon Nakhon	Phu Phan Formation	Kpp
WS20	West	Ban Lard	Ban Lard	Phetchaburi	No data	Kgr
WS21	West	Ban Nong Chik	Khao Yoi	Phetchaburi	No data	Kgr

In Northeastern region, cutting stone sources are found at Phu Phan Formation (Kpp) while in the Western region is no data of neither rock group nor rock unit (result based on shapefile data from Department of Mineral Resources). However, the stone workshop in Western region is broadly found at Igneous rock areas.

Cutting stone sources in Northeastern region (Khorat Plateau) are mostly sedimentary rock of Khorat group. It is formed in basins as a result of the collision between Shan-Thai and Indochina cratons (LTD and GGD 1997). Phu Phan Formation which consists of highly resistant sandstone and conglomerate, is one of rock units in Khorat group. It is found around the rim of Khorat Plateau. This rock unit may have been created by the accumulation of silt from braided stream since Cretaceous (120-100 million years ago) up until Tertiary (55 million years ago). The soil is caused by decomposition of rocks, including sandstone, shale, lime stone, quartzite, and phyllite (Office 1997).

The Phu Phan Formation consists of the sandstone and conglomerate, interbedded with siltstone and mudstone. Sandstone is coarse-grained with white, grayish white, greenish gray, brownish yellow, and pale brown colors, commonly with pebbly cross-bedding and thick-bedding structures. Pebbles within the conglomeratic sandstone comprise of white quartz, black chert, and brownish red siltstone which are rounded to sub rounded, and well cemented. The sequences are typically thick to very thick beds and interbedded with siltstone (LTD and GGD 1997). Rocks of this formation cover most of the hilly areas and some parts of the undulating terrains around edge of Khorat Plateau (Ichikawa, et al. 2008).

Igneous rock (Kgr) is found along the western edge of Western region and Peninsular. Kgr is used as the symbol of granite and granodiorite rock in Thailand (Chanyotha, et al. 2011). In southern Thailand, Cretaceous granitic rocks are formed as a batholith in the high mountain range (Chaturongkawanich and Leevongchareon 2000). USGS (1998) describes the granite rock unit (Kgr) as very light gray to light brown, medium to coarsely crystalline foliated granitic rock, largely quartz diorite with some granite. The rock is extremely fractured and deeply weathered, with an alignment of dark minerals and dioritic inclusions that is cut by tabular bodies of aplite and pegmatite that are generally parallel to foliation (Brabb and RW Jones 1998; Edwards, et al. 2015).

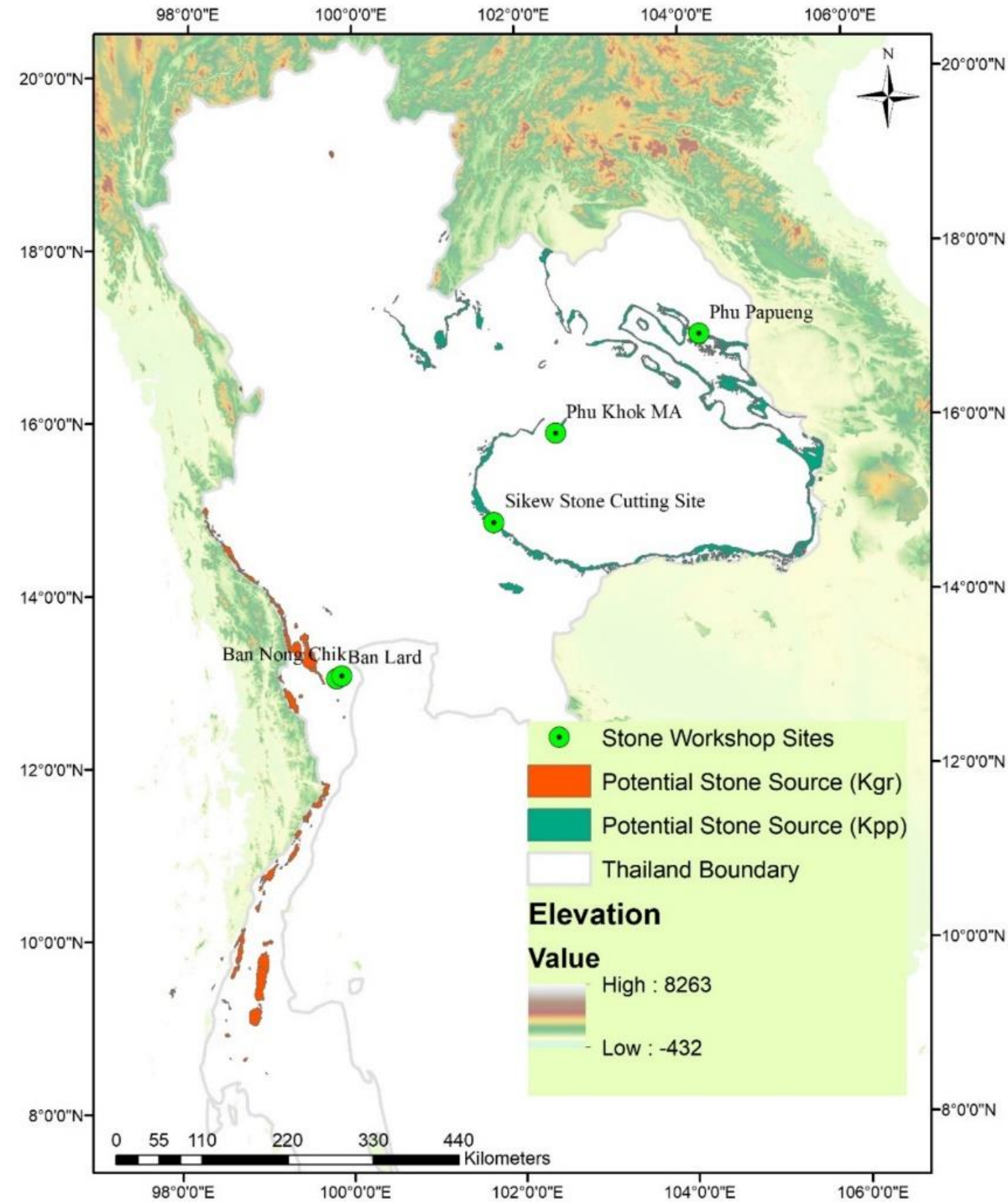


Figure 4.18: Potential stone workshop sources, map by Areerut Patnukao

4.2 The Spatial Distribution of Dvāravatī Settlements

To analyze the spatial distribution of Dvāravatī sites, several approaches and methods are used, including average site density, NNA, KDE, and rank-size analysis.

4.2.1 Site Density

In this section, 139 Ancient Town and Ancient Community are analyzed. At the national level, the density of Dvāravatī sites is 0.00027 sites/km^2. At the regional level, the Central Plain has the highest site density at 0.0023 sites/km^2 (Figure 4.19). In river basin level, Chao Phraya and Bang Prakong basins have the highest site density, 0.00168 sites/km^2 (Figure 4.20). There are several possibilities that may explain these differences in site densities. For instance, an inconsistency of archaeology survey and excavation throughout the country may cause variations of data in some areas. Moreover, presently inadequate available data may also alter the result of site density.

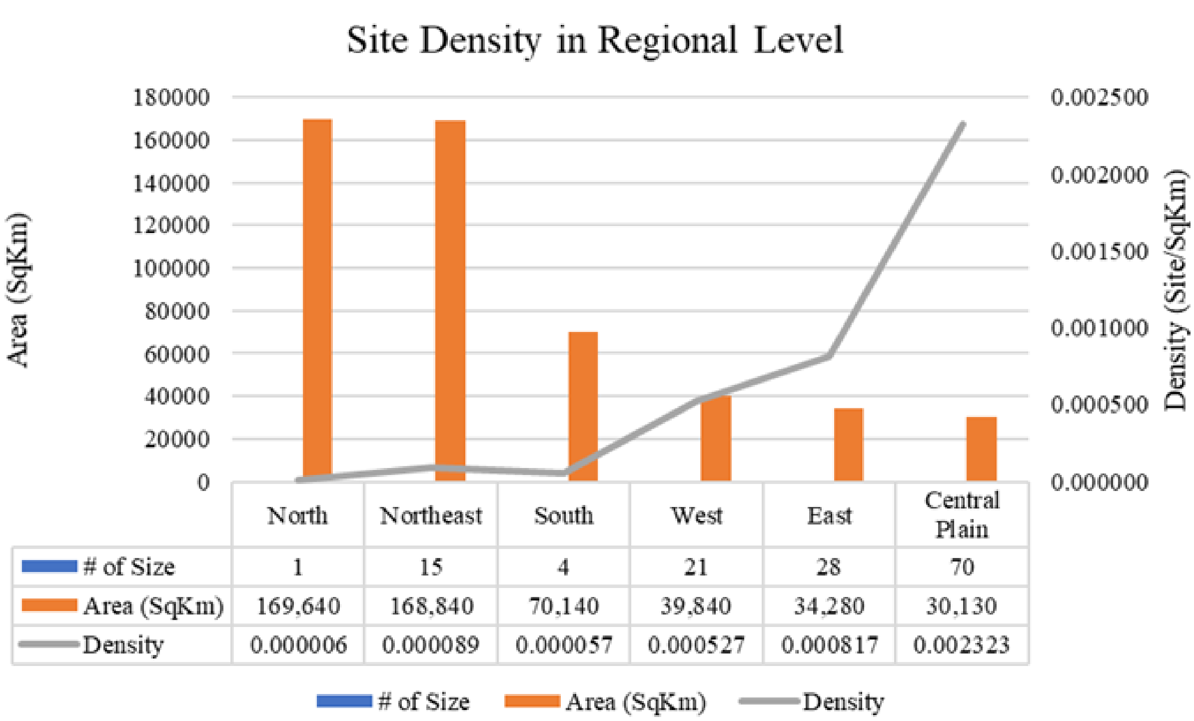
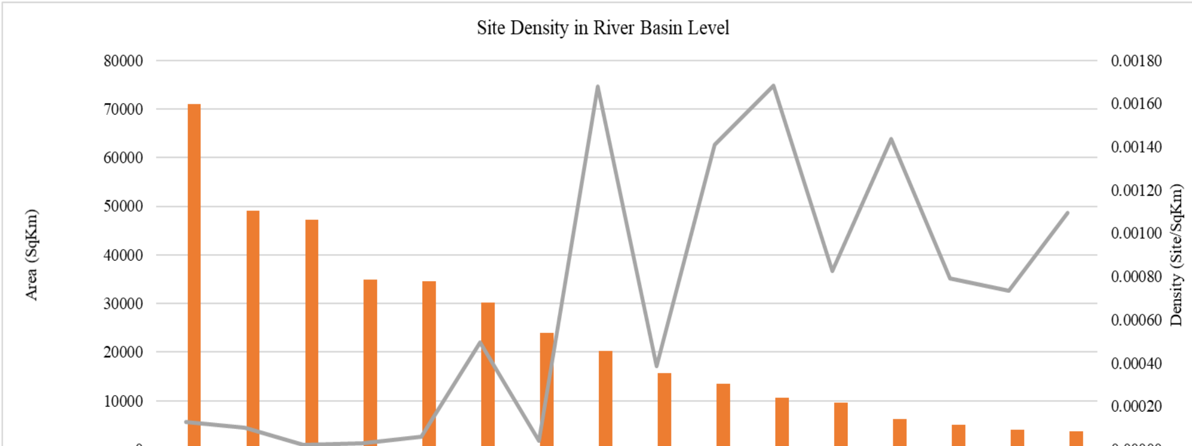


Figure 4.19: A histogram shows the area (in km^2) of each region sorted in ascending order and graph shows the site density in each region (site/km^2)



	Mun	Chi	Mekong (NE)	Nan	Ping	Mae Klong	Yom	Chao Phraya	Pa Sak	Tha Chin	Bang Prakong	Prachin Buri	Phetcha buri	Sakae Krang	Thole Sap	Pattani
# of Size	9	5	1	1	2	15	1	34	6	19	18	8	9	4	3	4
Area (SqKm)	71,071.	49,129.	47,154.	34,908.	34,499.	30,180.	23,948.	20,266.	15,623.	13,491.	10,700.	9,672.1	6,260.1	5,055.8	4,085.9	3,654.8
Density	0.00013	0.00010	0.00002	0.00003	0.00006	0.00050	0.00004	0.00168	0.00038	0.00141	0.00168	0.00083	0.00144	0.00079	0.00073	0.00109

Figure 4.20: A histogram shows the area (in km^2) of each river basin sorted in ascending order and graph shows the site density in each river basin (site/km^2)

This study shows the different result when compares to the previous studies which focused on particularly small areas and did not use only the sites in Dvāravatī period. Thus, the site density in this study is much lower than those studies. For instance, Mudar (1993) studied the site density in the Lam Maleng Valley in Chao Phraya basin in Central plain. The result shows that overall site density is 1.68 sites/km^2 (Mudar 1993: Table 5.1, p. 78). Besides, the site density is 0.92 sites/km^2 in alluvial plain and 2.3 sites/km^2 in upland area (Mudar 1993). In Northeastern region, Welch and MacNeil (1990:27) identified site density at 0.21 sites/km^2 on the alluvial plain in the Mun river valley, and 0.04 sites/km^2 on the higher terraces in Phimai region (Welch and McNeill 1991).

Generally, the site densities in this study are much lower than previous studies since this study considered only two types of sites which are Ancient Town and Community that were occupied during Dvāravatī period. Besides, the study areas are considerably large even though the analyses are performed in three different geographic levels. Therefore, it cannot be certain of the correct interpretation without applying intensive surveys or additional data in the further future research.

4.2.2 Nearest Neighbor Analysis (NNA)

The results of NNAs of 139 Ancient Town and Ancient Community sites in three different geographic levels, as well as 59 moated sites in national level are presented in the Table 4.5. The Nearest Neighbor Ratio (NNR) is the ratio between the Observed Mean Distance (OMD) and the Expected Mean Distance (EMD). If a value of NNR <1 means sites are clustered. A value of NNR = 1 indicates a random pattern. If the value of NNR >1 means points are dispersed (Levine 2013). In ArcMap, if the values of z-score is in between -1.65 to 1.65, it results in random pattern. A z-score greater than 1.65 indicates a dispersed pattern. Alternatively, a z-score less than -1.65 indicates a clustered pattern.

Figure 4.21 shows normal distribution curves showing nearest neighbor statistics and a clustered pattern of Ancient Town and Community sites as well as moated sites in national level. Figure 4.22 illustrates the spatial patterns of sites at regional level. Figure 4.23 presents normal distribution curves showing nearest neighbor statistics and various patterns in regional level. The clustered pattern is occurred only in Eastern region. The random pattern is appeared in Central Plain and Western regions. The dispersed pattern is existed in Northeastern and Southern regions. Figure 4.24 displays spatial patterns of sites in river basin level. Figure 4.25 illustrates normal distribution curves showing nearest neighbor statistics and only random pattern in river basin level. The random pattern is presented only in Bang Prakong, Chao Phraya, Prachin Buri, and Tha Chin river basins. Figures 4.26 and 4.27 present normal distribution curves showing nearest neighbor statistics and only dispersed pattern in river basin level. The dispersed pattern is the most common pattern in river basin level, including Chi, Mae Klong, Mun, Pa Sak, Pattani, Phetchaburi, Ping, Sakae Krang, and Thole Sap river basins. The clustered pattern is not present at the river basin level. It should be noted that the ANN analysis tool could not perform the analysis in Northern region, as well as Mekong (NE), Nan, and Yom river basins since each of them has only one feature. The tool requires at least two features to compute the results.

Table 4.5: Nearest Neighbor Analysis (NNA) of sites in three different geographic levels

Level	Sub-level	OMD (m)	EMD (m)	NNR	Z-Score	P-Value
Nation	139 AT and AC sites	15119.2437	37752.095	0.400488	-13.521862^{C}	0
	59 Moated sites	20053.2371	25928.7365	0.773398	-3.329817^{C}	0.000869
Region	Central Plain	13989.2936	15242.6553	0.917773	-1.316121^{R}	0.188134
	East	9581.1598	12131.614	0.789768	-2.128183^{C}	0.033322
	Northeast	36128.7557	29341.513	1.231319	1.713907^{D}	0.086546
	South	830.2122	97.9136	8.47903	28.615817^{D}	0
	West	14116.8786	13658.295	1.033575	0.301276^{R}	0.763204
River Basin	Bang Prakong	8918.4823	7711.5135	1.156515	1.27035 ^{R}	0.20396
	Chao Phraya	10988.6182	11253.3556	0.976475	-0.262424^{R}	0.792995
	Chi	44618.6122	28586.808	1.560811	2.399013^{D}	0.016439
	Mae Klong	21365.294	16719.474	1.277869	2.05881^{D}	0.039512
	Mun	35491.0533	24907.239	1.424929	2.438758^{D}	0.014738
	Pa Sak	24399.4836	13462.847	1.812357	3.806741^{D}	0.000141
	Pattani	830.2122	97.9136	8.47903	28.615817^{D}	0
	Phetchaburi	6659.0132	5224.6816	1.27453	1.660812^{D}	0.096751
	Ping	251037.271	244.9954	1024.661004	2769.50427^{D}	0
	Prachin Buri	4333.1227	5268.2325	0.8225	-0.960447^{R}	0.33683
	Sakae Krang	15485.8487	6182.7973	2.504667	5.757067^{D}	0
	Tha Chin	8716.3669	9542.4101	0.913435	-0.721859^{R}	0.470381
	Thole Sap	14102.8899	4137.5889	3.40848	7.980582^{D}	0

*Note: Region: North; River Basin: Mekong (NE), Nan, and Yom cannot be analyzed since has only one feature, the tool requires at least 2 features to compute results
AT= Ancient Town, AC= Ancient Community
^{C}=Clustered, ^{D}=Dispersed, ^{R}=Random

National Level

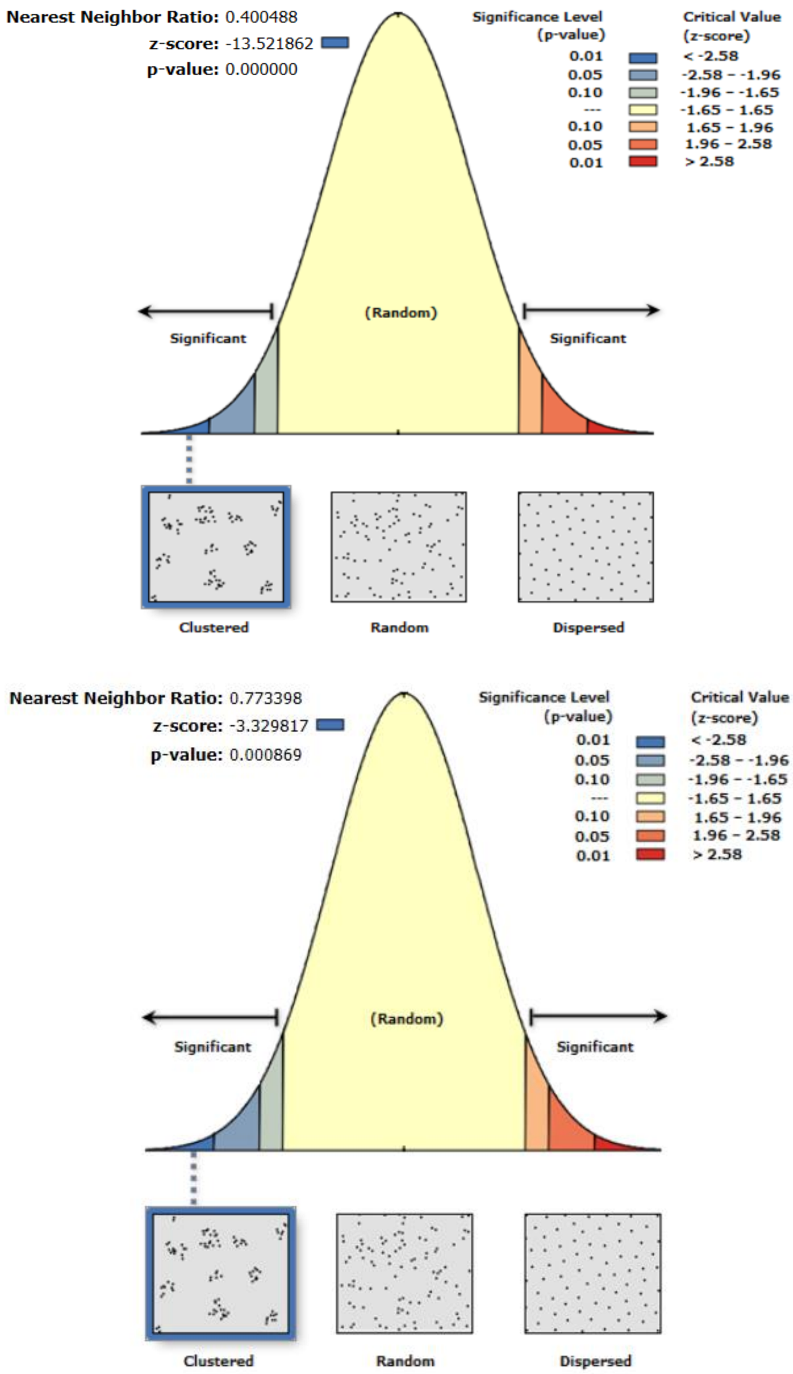


Figure 4.21: Normal distribution curves showing nearest neighbor statistics and clustered pattern in national level: 139 Ancient Town and Community sites (Upper), 59 moated sites (Lower)

Regional Level

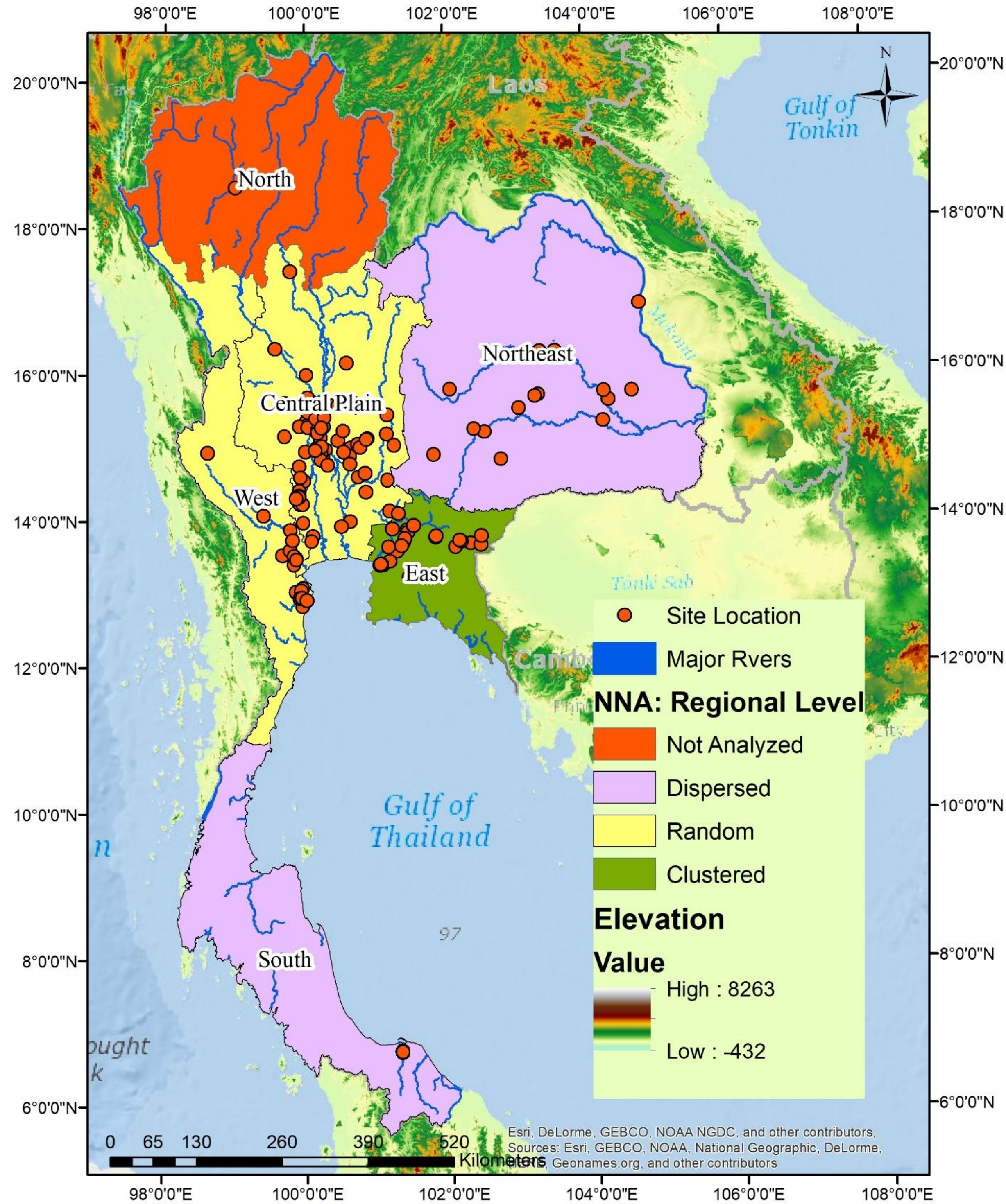


Figure 4.22: A map showing spatial patterns of sites in regional level

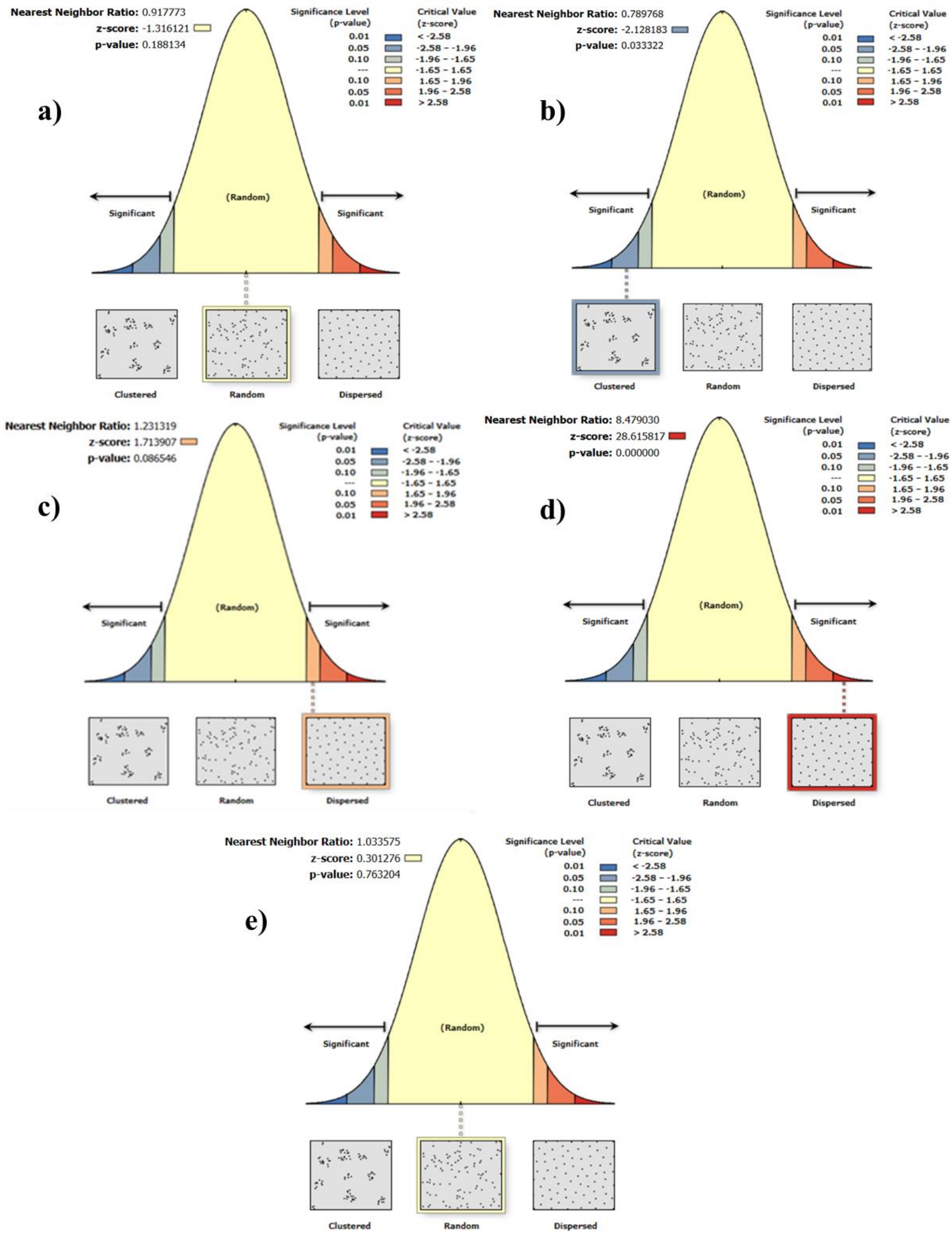


Figure 4.23: Normal distribution curves showing nearest neighbor statistics and patterns in regional level: a) Central Plain-random, b) East- clustered, c) Northeast-dispersed, e) South-dispersed, and f) West-random

River Basin Level

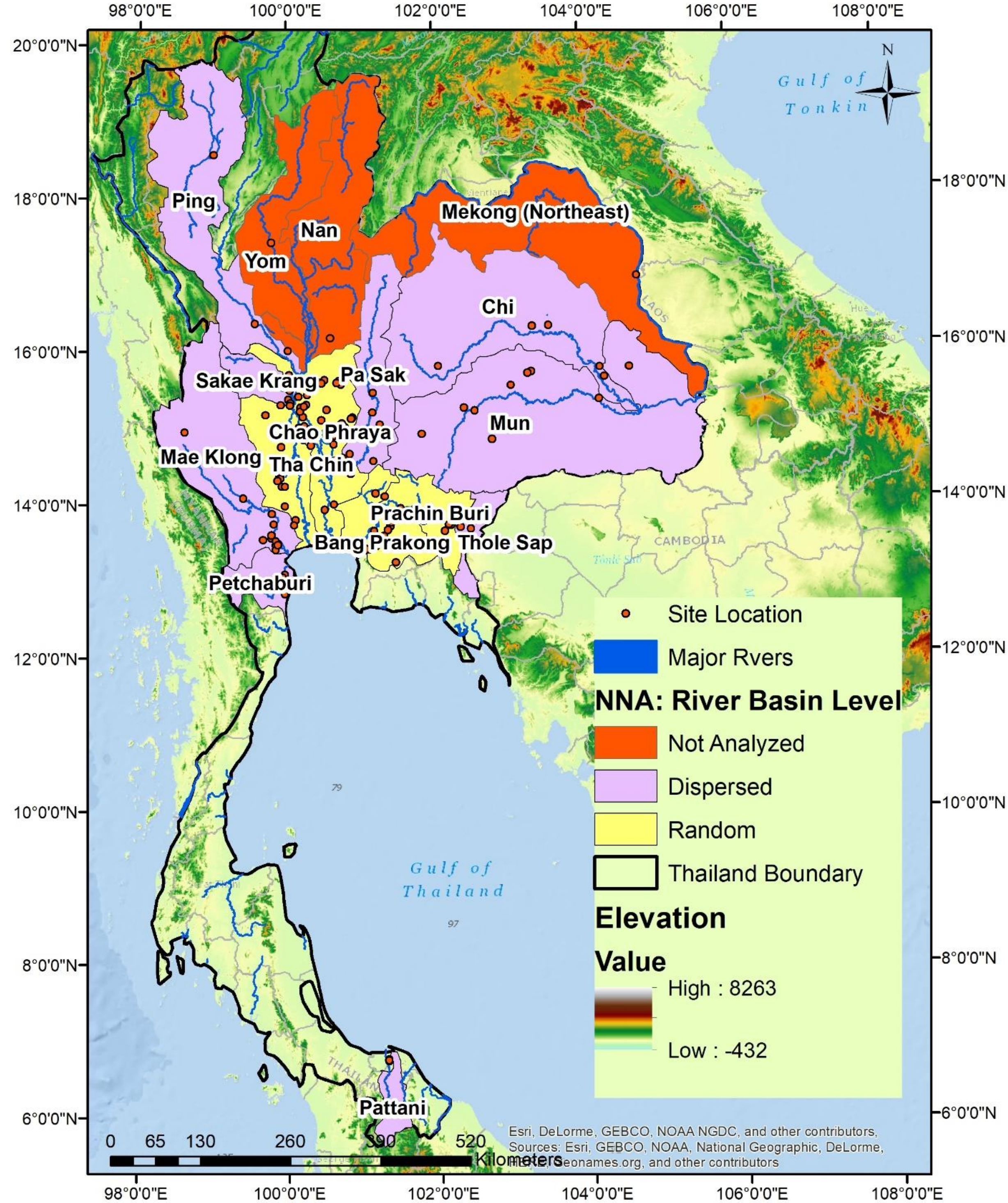


Figure 4.24: A map showing spatial patterns of sites in river basin level

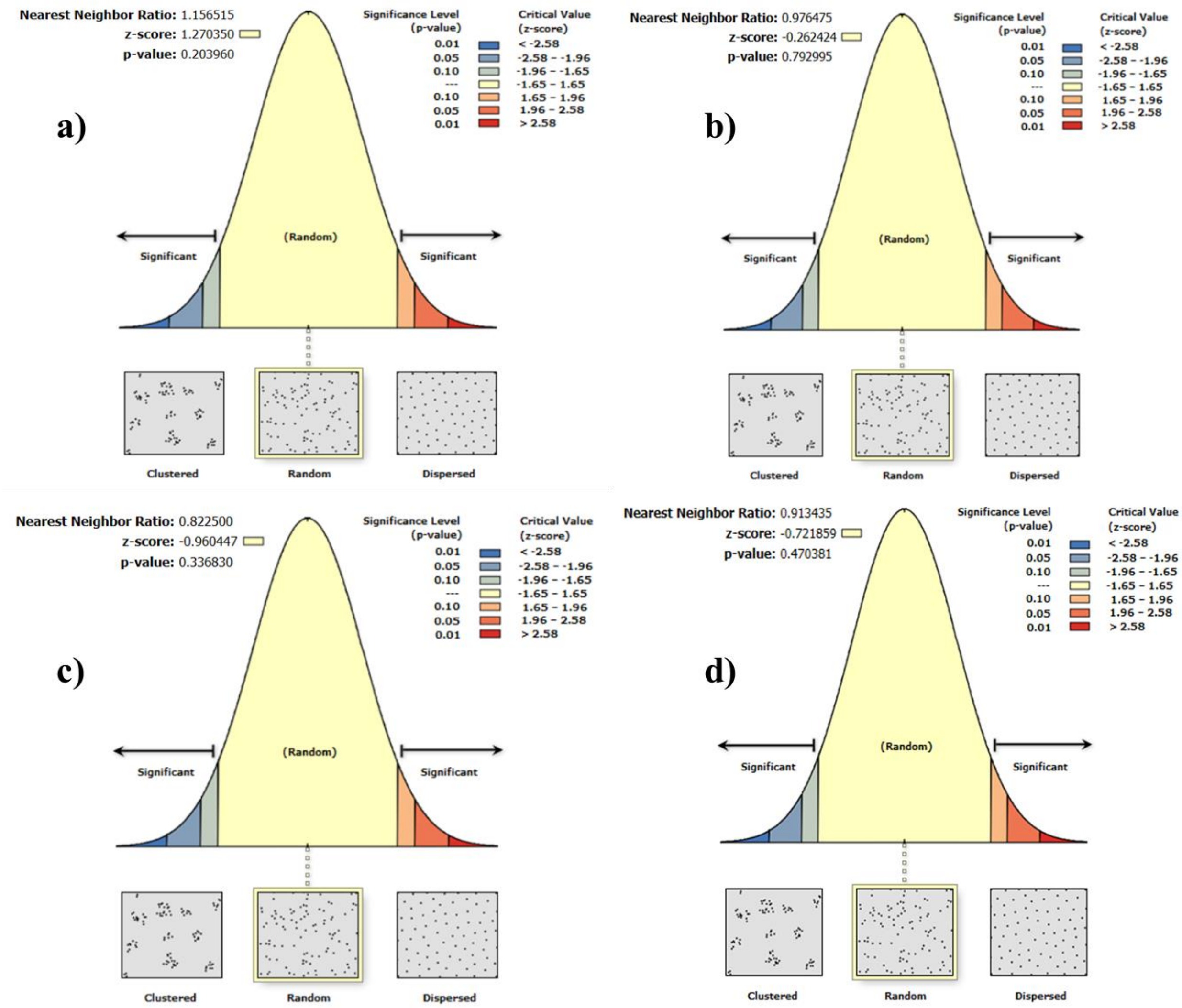


Figure 4.25: Normal distribution curves showing nearest neighbor statistics and only random pattern found in river basin level: a) Bang Prakong, b) Chao Phraya, c) Prachin Buri and d) Tha Chin river basins

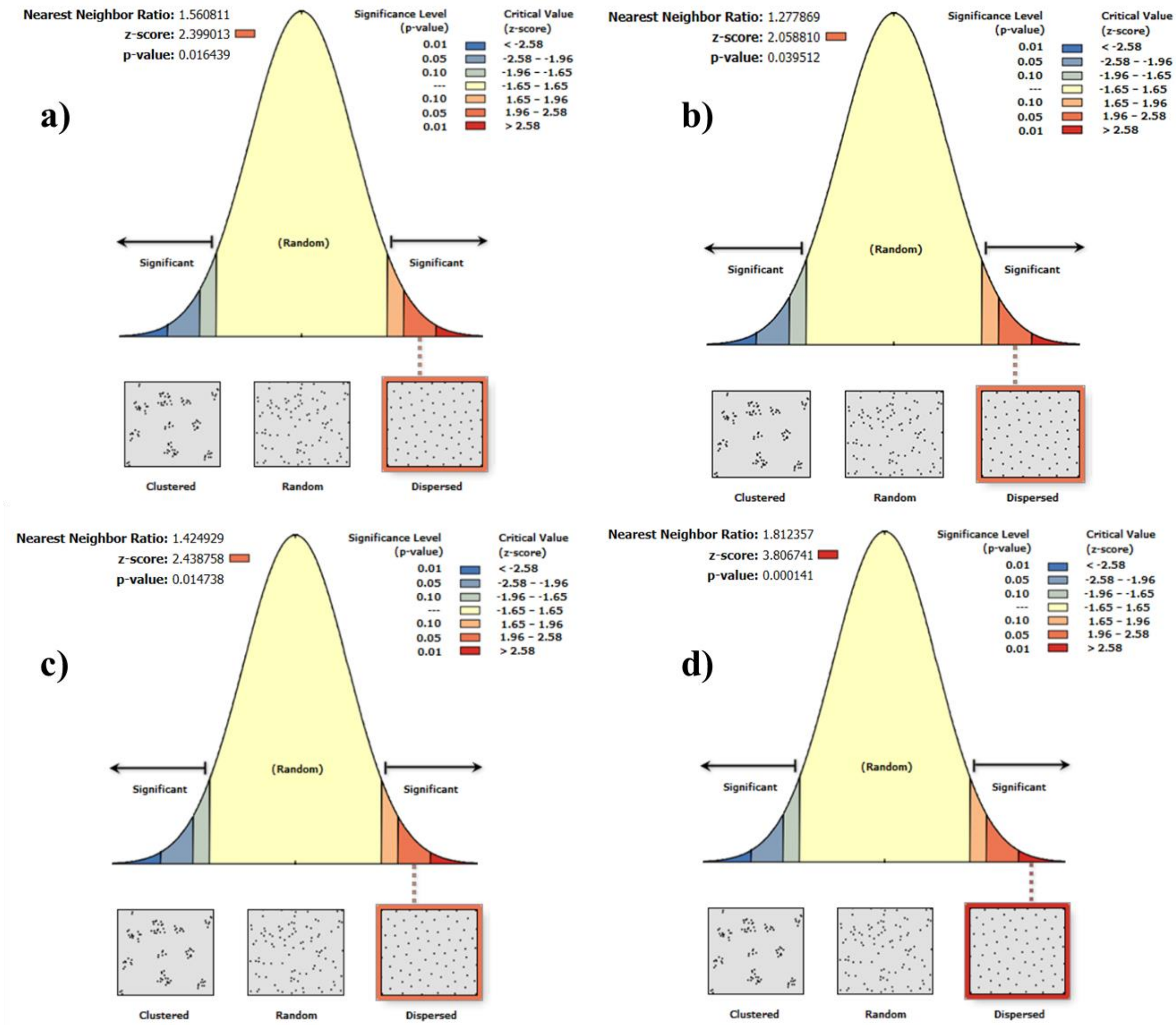


Figure 4.26: Normal distribution curves showing nearest neighbor statistics and only dispersed pattern found in river basin level: a) Chi, b) Mae Klong, c) Mun, and d) Pa Sak river basins

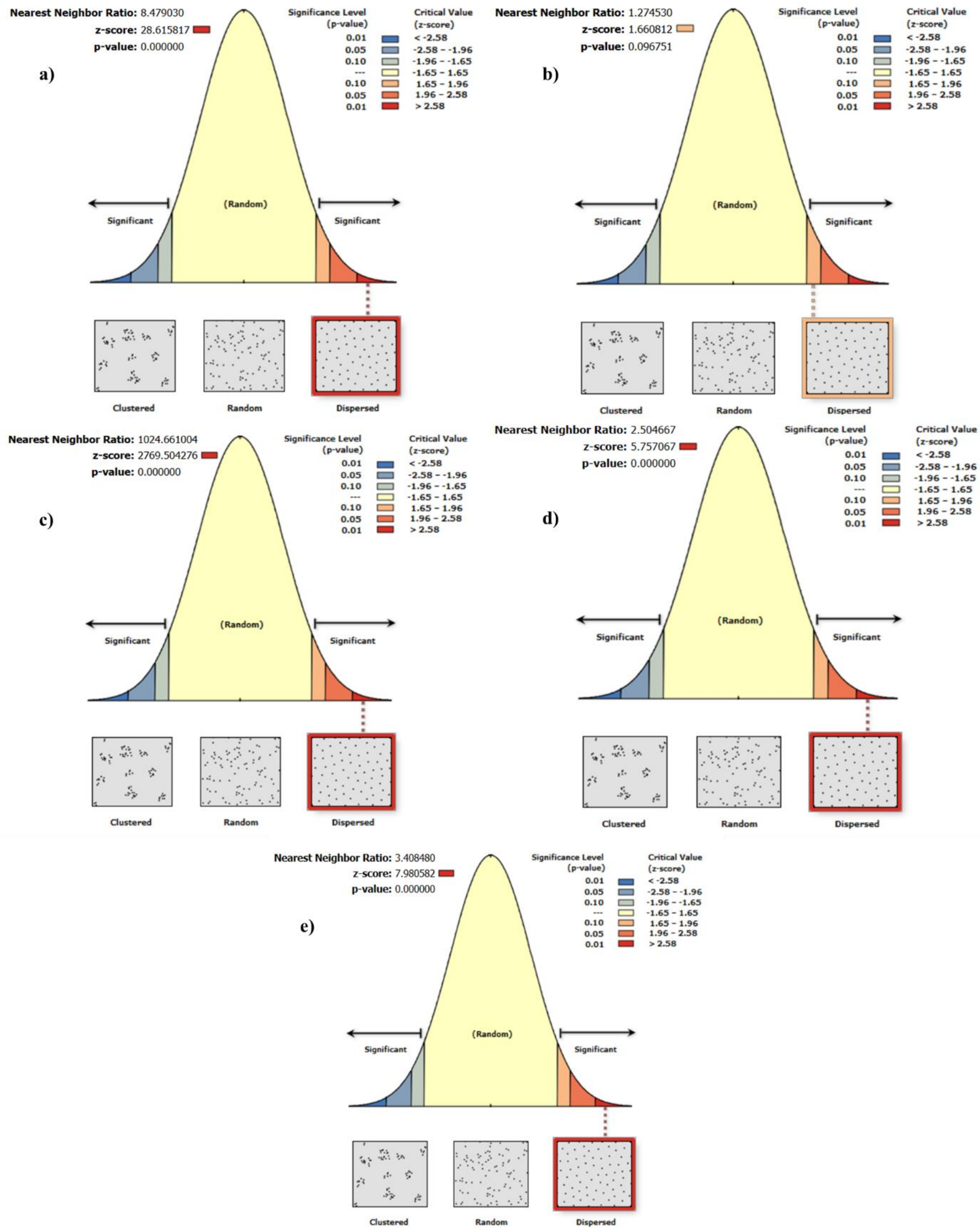


Figure 4.27: Normal distribution curves showing nearest neighbor statistics and only random pattern found in river basin level: a) Pattani, b) Phetchaburi, c) Ping, d) Sakae Krang, and e) Thole Sap river basins

4.2.3 Kernel Density Estimate (KDE)

The results from KDE analysis are color-ramped in brown, with the darker shades indicating increase site densities. The application of KDE method confirms that the greatest density is found in Central area and expanded northeastward to Northeastern region. However, the site density is not constant through the region.

National Level

In national level, the KDE method is used to test three different data sets, all site types (425 sites), Ancient Town and Ancient Community site types (139 sites), and 59 moated sites. For all site types, the greatest density is found in the Mae Klong and Tha Chin river basins and expanded northeastward (Figures 4.28a and 4.29a). It should be noted that the northeastward trend may be a result of including 93 Sema sites from Murphy's (2010) study which significantly cause an increase number of sites the Northeastern region. For Ancient Town and Ancient Community site types, the Upper Chao Phraya river basin has the greatest density. Eastern region (Bang Prakong river basin) seems to be second highest density area and the third highest density area is around western region (Figures 4.28b and 4.29b). For moated sites, the greatest density is formed around the Upper Chao Phraya river and its tributaries which covers the intersections of Chai Nat, Sing Buri, Lop Buri, Nakhon Sawan, and Suphan Buri Provinces and extended outward (Figures 4.28c and 4.29c).

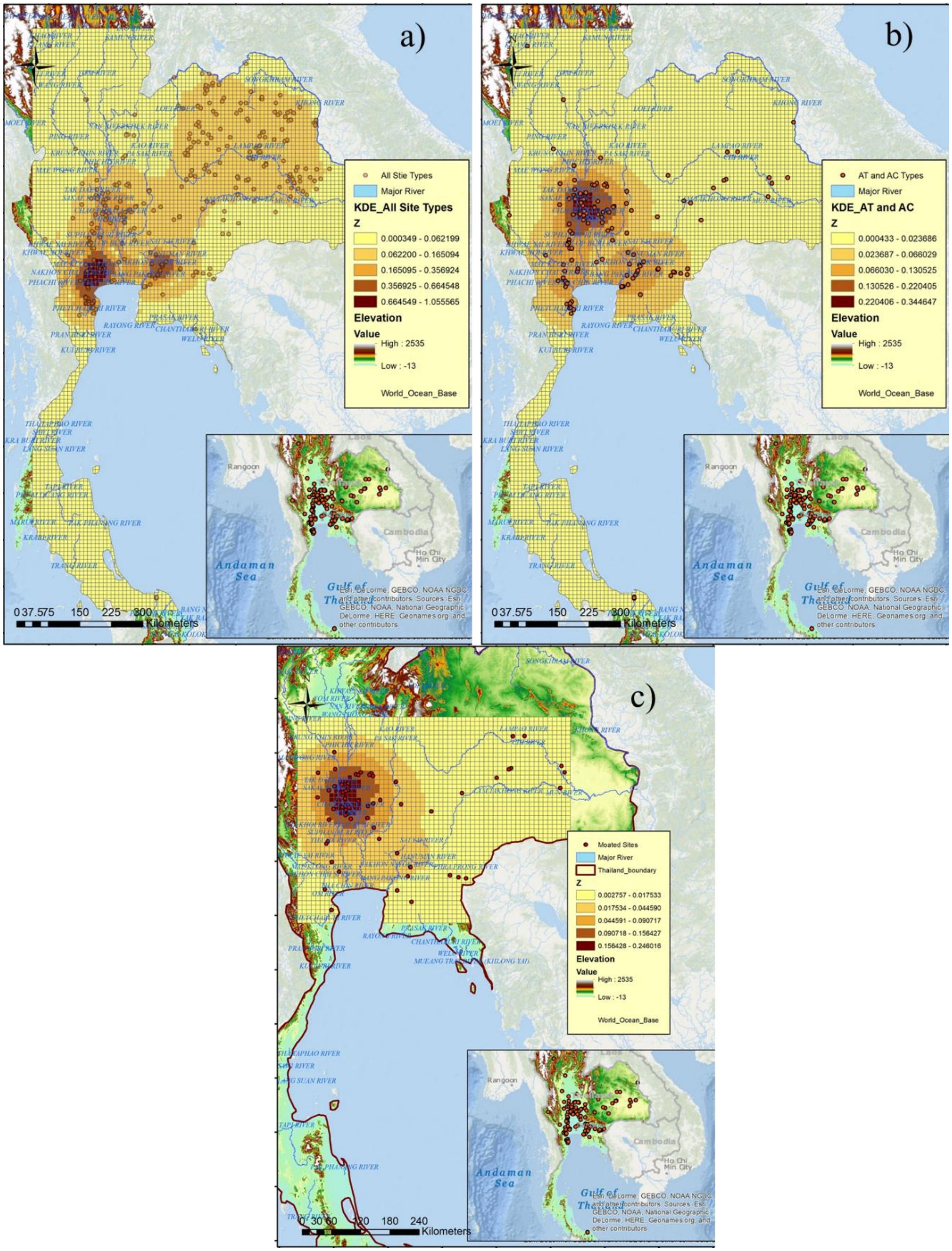


Figure 4.28: KDE results in national level: a) all site types, 425 sites; b) only Ancient Town and Ancient Community types, 139 sites; c) only moated sited, 59 sites; map by Areerut Patnukao, basemap from Esri and other contributors

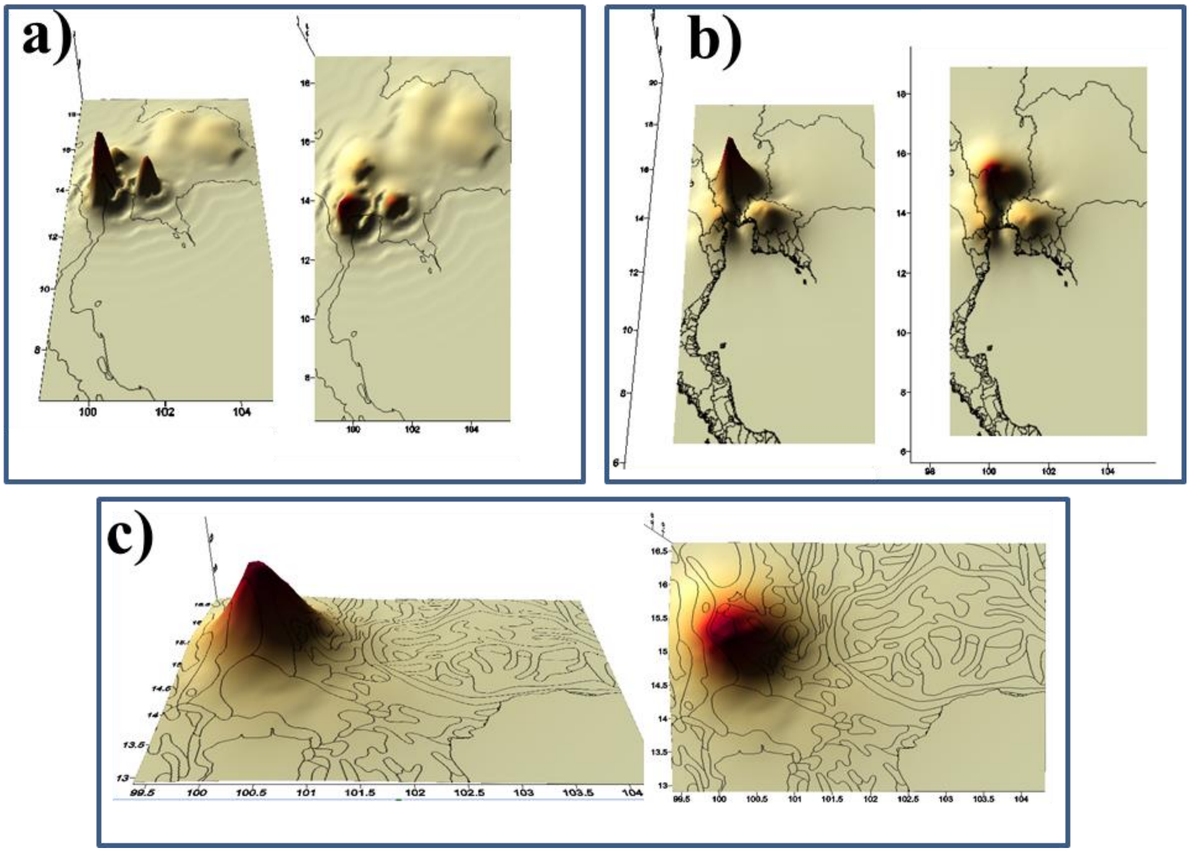


Figure 4.29: 3D surfaces showing site density in national level**;** a) all site types, 425 sites; b) only Ancient Town and Ancient Community site types, 139 sites; c) only moated sited, 59 sites

Regional Level

Only three regions, Central Plain, East, and West, which have the number of sites equal or higher than 19, are analyzed by KDE. In the Central Plain region, the greatest density is formed circularly around the intersections of tributaries of Upper Chao Phraya river basin nearby Chai Nat and Sing Buri provinces (Figures 4.30a and 4.31a). In the Eastern region, high density is occurred along Bang Prakong river basin. The greatest density is shown on the east side of the mouth of Bang Prakong river (Figures 4.30b and 4.31b). In the Western region, there are two centers of greatest density which are Mae Klong river basin (around Ku Bua site) in the north and Phetchaburi river basin in the south (Figures 4.30c and 4.31c).

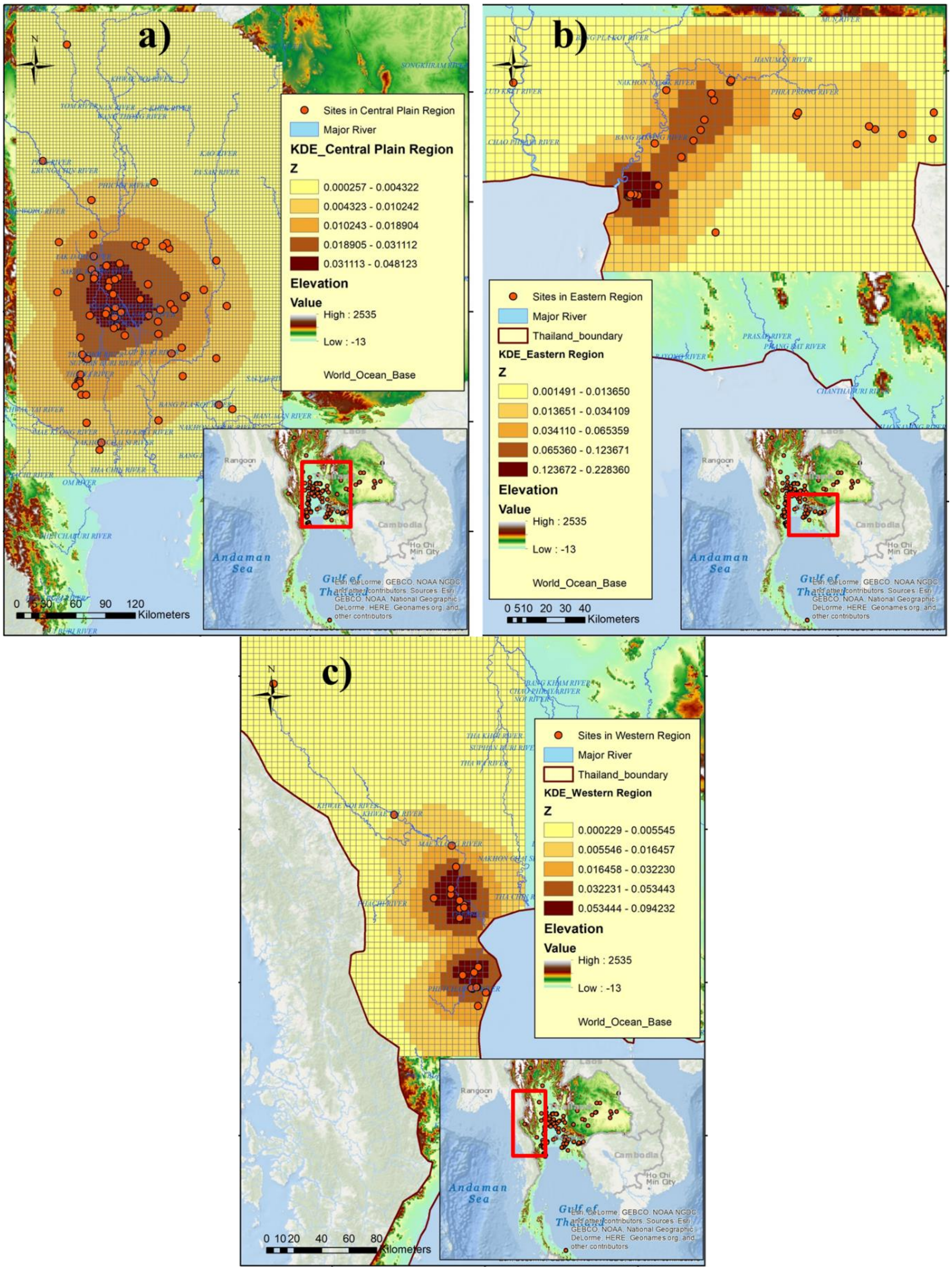


Figure 4.30: Site density in regional level: a) Central Plain, b) East, c) West, map by Areerut Patnukao, basemap from Esri and other contributors

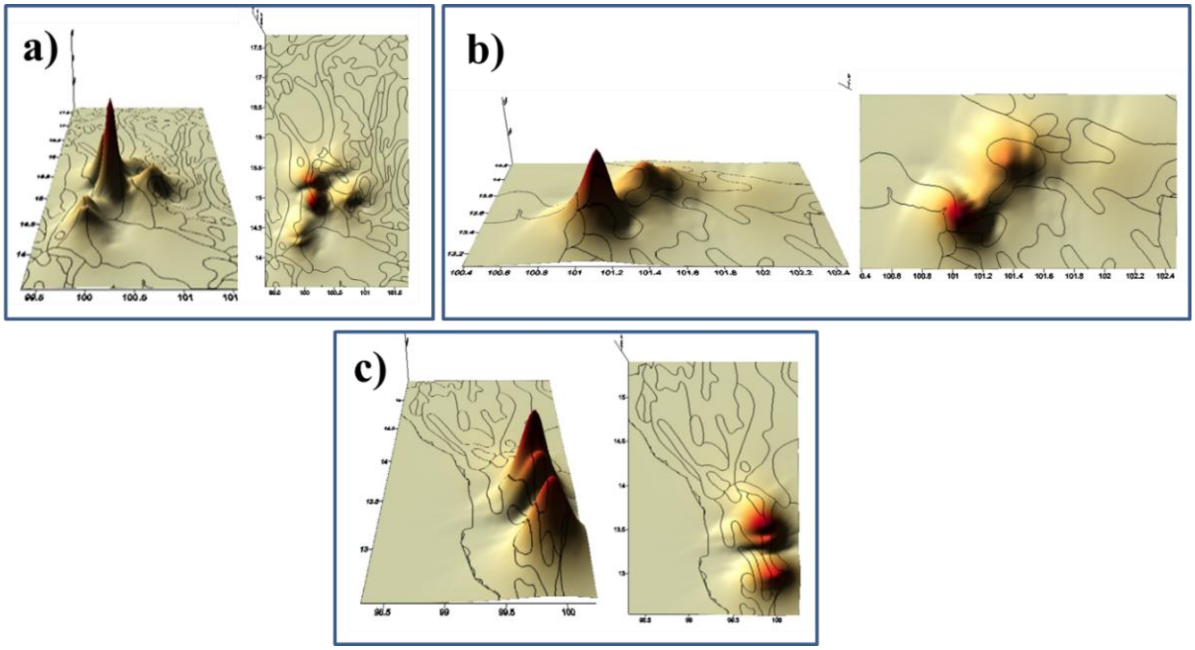


Figure 4.31: 3D surfaces showing site density in regional level: a) Central Plain, b) East, c) West

River Basin Level

Only Chao Phraya and Tha Chin river basins are analyzed since these two basins have sites equal or higher than 19 sites. In Chao Phraya river basin, the greatest site density formed around the river basin and gradually decreased outward (Figures 4.32a and 4.33a). While in the Tha Chin river basin, site density is formed along the geographic shape of Tha Chin river and has higher density on the western side of the river (Figures 4.32b and 4.33b).

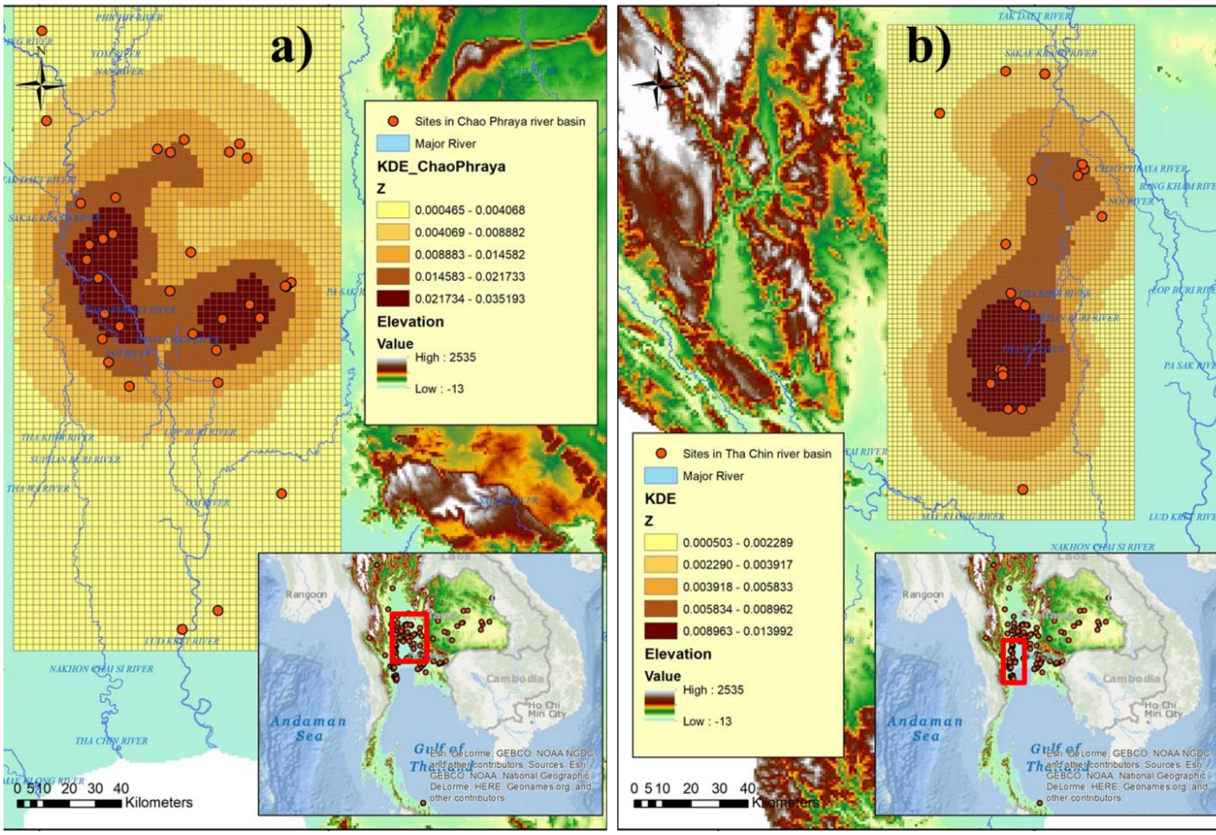


Figure 4.32: Site density in river basin level: a) Chao Phraya, b) Tha Chin, map by Areerut Patnukao, basemap from Esri and other contributors

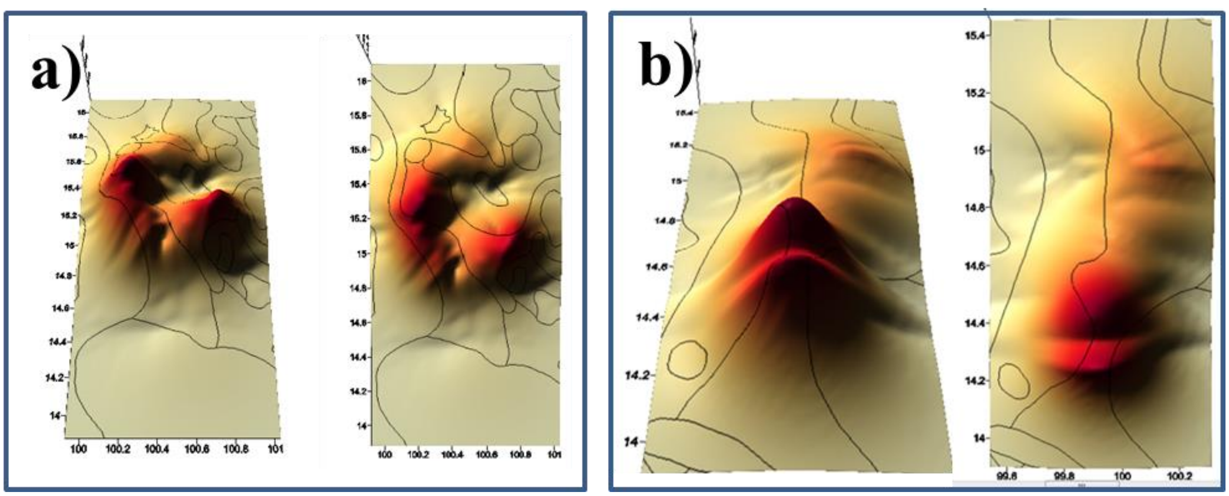


Figure 4.33: 3D surfaces showing site density in river basin level: a) Chao Phraya, b) Tha Chin

4.2.4 Rank-Size Distribution

Due to the presently available data, only 59 moated sites are used to perform rank-size analysis. These sites are only Ancient Town sites. The analysis result shows significant clustered pattern around the major rivers in Central Plain. The sizes of moated range from 0.01 km^2 to more than 6 km^2. By using natural breaks classification in ArcMap, these site sizes can be roughly classified into 5 classes (Figure 4.34).

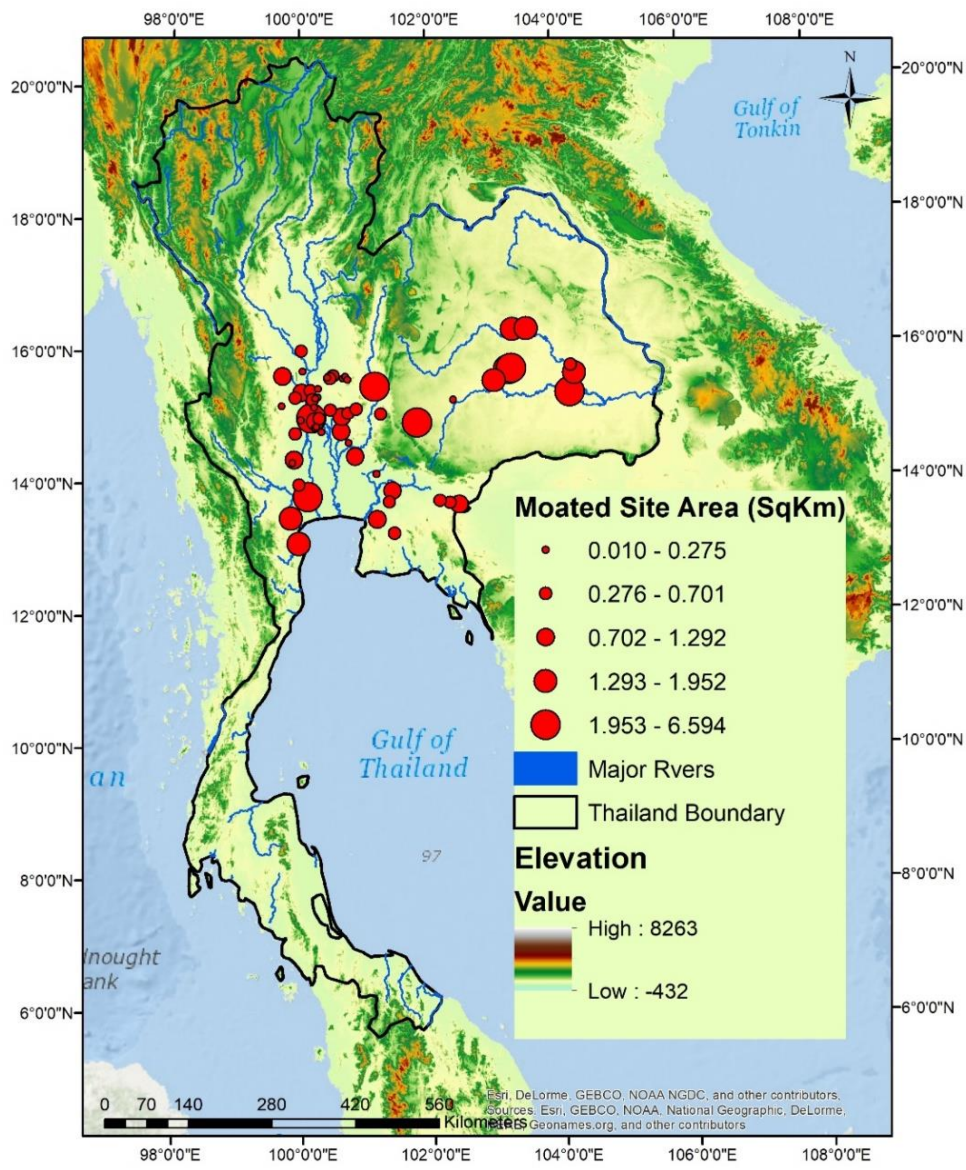


Figure 4.34: Spatial distribution of moated sites, map by Areerut Patnukao, basemap from Esri and other contributors

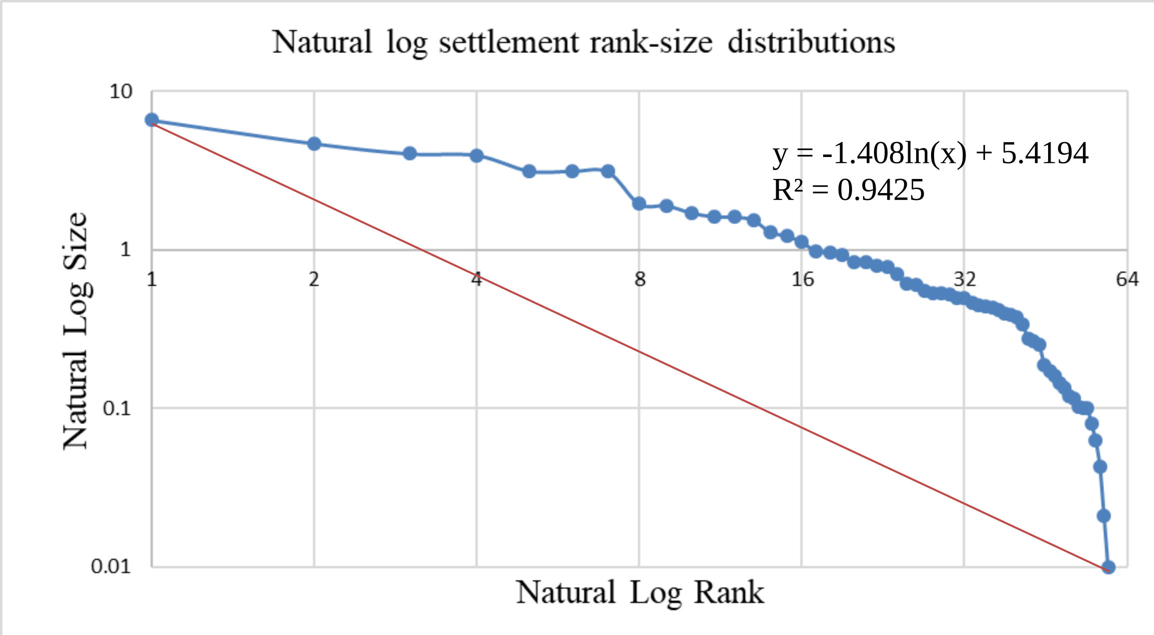


Figure 4.35: Natural log settlement rank-size distributions

Figure 4.35 presents the rank-size distribution of 59 moated sites in log-normal distribution. Dvāravatī settlement follows a convex pattern which indicates that several large settlements have similar size. This curve indicates that the rank-size configuration of the sample sites lies above a line with slope of -1. The curve serves as a useful indicator of some broad aspects of the Dvāravatī settlement system. Archaeological and historical data are used to suggest that a convex pattern can be attributed to low system integration (Johnson 1980). It may indicate that settlements of two independent social systems have been integrated among settlements. Each settlement was inhabited by an autonomous social group (Mudar 1999). It may indicate a low level of national integration exists (Sonis and Grossman 1989). Johnson (1977:498) noted that convex distributions normally appear when the size distribution of a settlement system really approaches the discontinuous hierarchy suggested by central place theory with multiple highest order central places. Additionally, where communication is hindered by topography and poor transportation networks, interaction between adjacent systems is low and the settlement system is prone to have a convex curve (Johnson 1977).

Mudar (1999) studied the rank-size distribution of moated settlements in Central Plain of Thailand. Her study shows the lack of a convex pattern which suggest that by the end of the first millennium CE., this area was integrated into a single system and Nakhon Pathom was the 'primate center'. Presently, there is no evidence to indicate a site larger than Nakhon Pathom, hence Nakhon Pathom was growing over other settlements through monopoly of resources (Mudar 1999).

However, the result from this study is different from Murder's (1999) study since she focused only on the sites in the Central Plain. She did not include other large sites from other regions, for instance, Si Thep (in northern Central Plain) or Muang Nakon Jampasri (in Northeast). Nevertheless, the result may be different when available additional data is applied in the further study.

4.3 The Spatial Distribution of Dharmacakra Locations

Overall, there are 80 Dharmacakra items, out of which 49 were collected from fieldwork and 31 items are from previous studies (see detail in Appendix B Table B.2). The art style classification is based on Brown's (1996) and Indorf's (2014). It should be mentioned that there are four Dharmacakras that could not identify the original locations. The rests, 76 items, came from 31 sites (Figures 4.36 and 4.37). Among these sites, Nakhon Pathom (CS49) contains the greatest number of Dharmacakras, 17 items. Si Thep (CS74) contains the second greatest number which is 8 items. Sab Champa (CS91) holds the third place with 6 items. It should be noted that there are several numbers of Dharmacakras whose origins are not traced but are currently stored at museums, for instance at Phra Pathom Chedi National Museum. In the past, since there was no systematic record or excavation, these items may had been transported from other places to be stored at the same place such as temples or the city centers. This could possibly explain why Nakhon Pathom contains the greatest number of Dharmacakras.

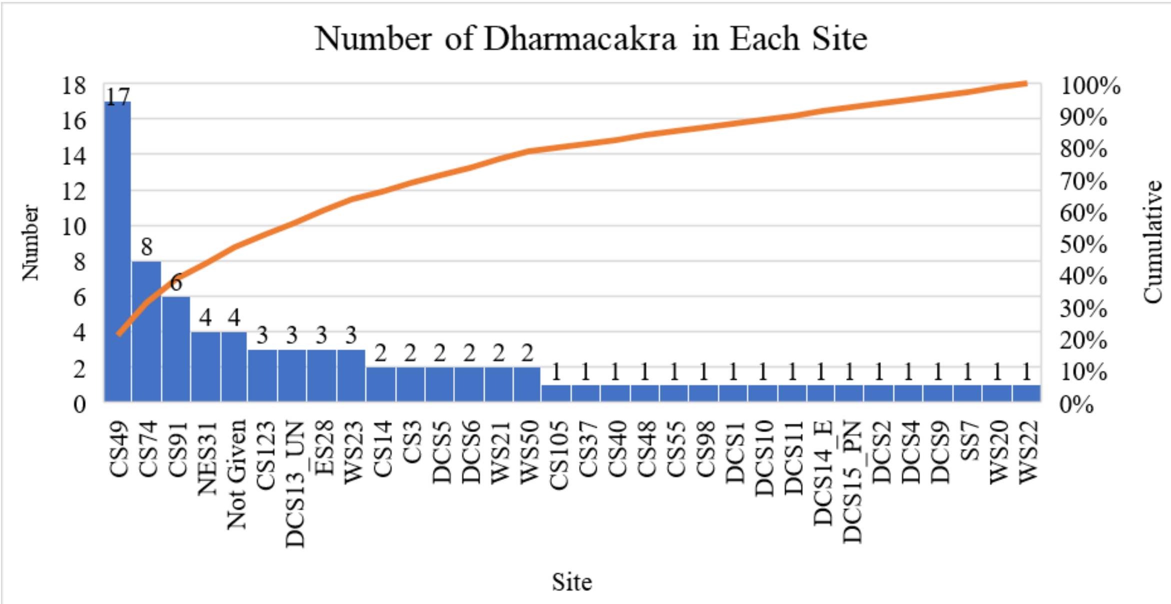


Figure 4.36: Graph shows the frequency of Dharmacakras located in each site with a cumulative (%) of the total

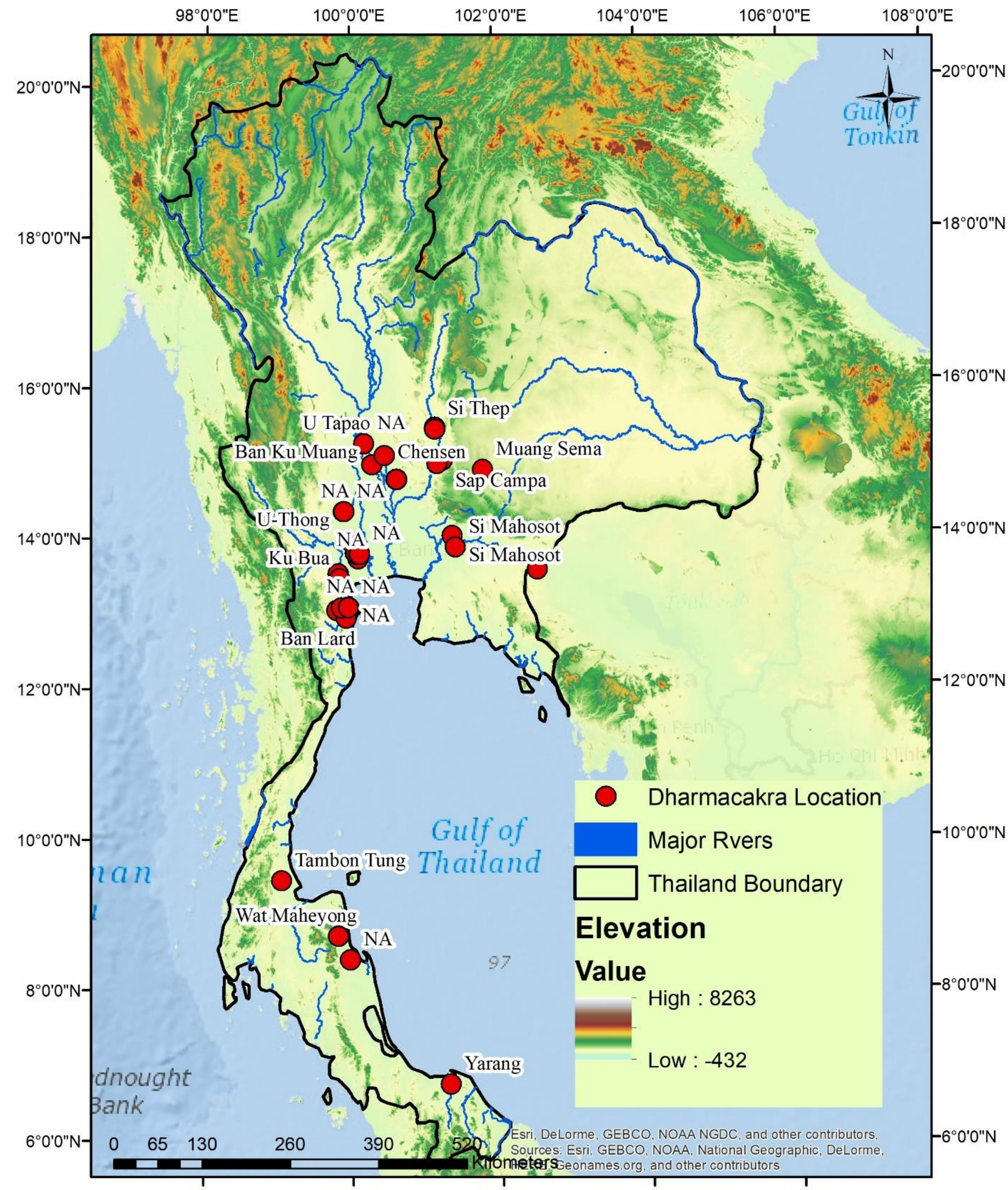


Figure 4.37: Spatial distribution of Dharmacakra locations, map by Areerut Patnukao, basemap from Esri and other contributors

4.3.1 Nearest Neighbor Analysis (NNA)

The result from NNA shows the clustered pattern of Dharmacakra locations across the country. The Observed Mean Distance is equal to 28693.5516 m, the Expected Mean Distance is 47709.6952 m which gives the Nearest Neighbor Ratio equals to 0.601420, z-score = -4.245487, and p-value = 0.000022 (Figure 4.38).

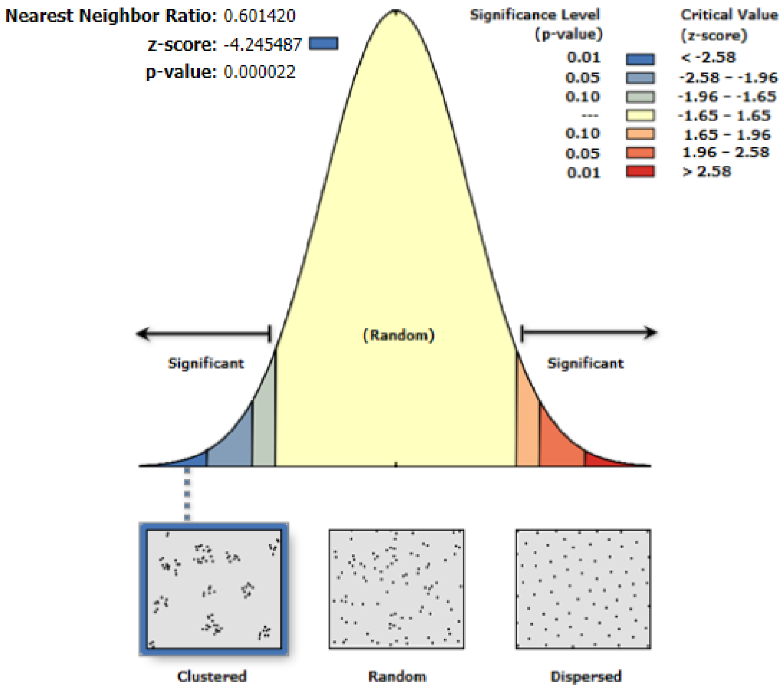


Figure 4.38: Normal distribution curves showing nearest neighbor statistics and clustered pattern of Dharmacakra throughout country

4.3.2 Kernel Density Estimate (KDE)

The result from KDE shows the greatest density of Dharmacakras around Lower Central Plain which the greatest density is found around Mae Klong river basin (Nakhon Pathom) and expanded outward. The second highest density is occurred around Pa Sak river basin where Si Thep and Sab Champa are located, these locations are second and third place respectively (Figures 4.39 and 4.40).

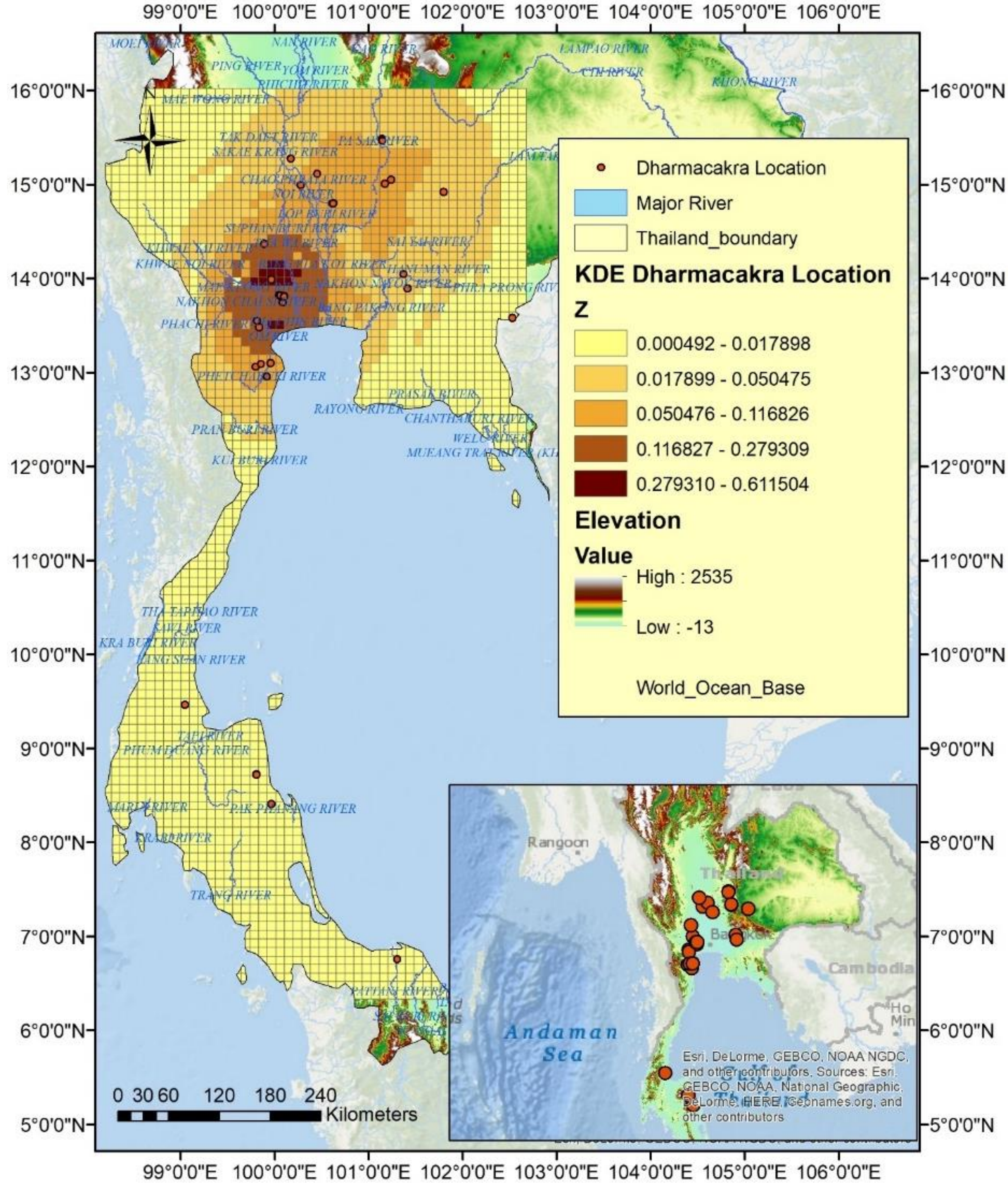


Figure 4.39: Dharmacakra location density across the country, map by Areerut Patnukao, basemap from Esri and other contributors

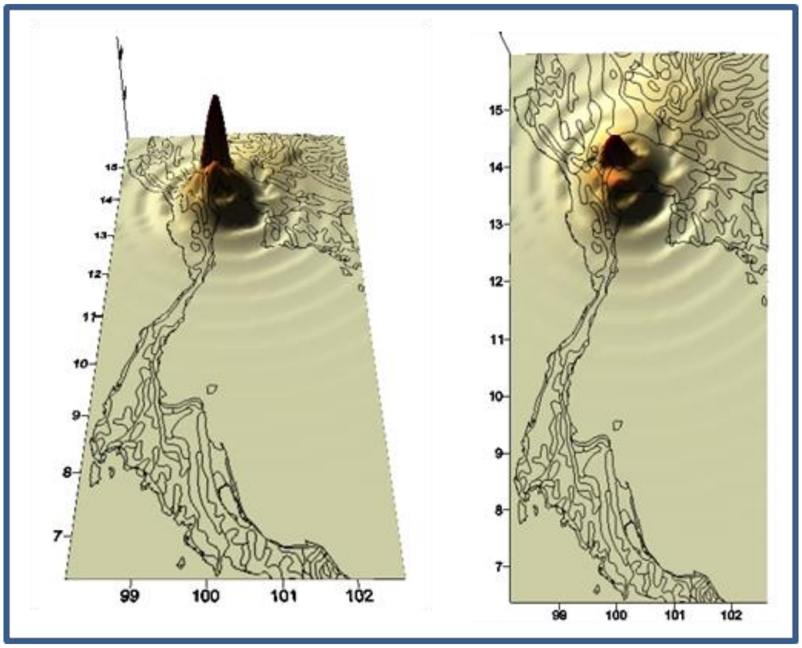


Figure 4.40: 3D surfaces showing Dharmacakra density across the country

4.3.3 Rank-Size Distribution

Owing to currently available data, there are 13 moated sites in which 52 Dharmacakras were found (Table 4.6). The rank-size distribution of these moated sites is tested. The result shows a convex pattern which gives the same pattern of moated sites' rank-size analysis (Figure 4.41).

Table 4.6: Number of Dharmacakras found in moated sites arranged in rank size order

Rank	Area (SqKm)	Site_ID	Site Name	# of Items	%
1	6.594	CS49	Nakhon Pathom	17	32.69
2	4.692	CS74	Si Thep	8	15.38
3	3.953	NES31	Muang Sema	4	7.69
4	1.710	WS50	Ku Bua	2	3.85
5	1.610	WS23	Phetchaburi	3	5.77
6	1.292	CS98	Lop Buri	3	5.77
7	0.980	ES28	Si Mahosot	1	1.92
8	0.963	CS123	U Thong	3	5.77
9	0.613	CS91	Sap Champa	6	11.54
10	0.547	CS3	U Tapao	2	3.85
11	0.525	CS48	Kamphaeng Saen	1	1.92
12	0.465	CS105	Ku Muang (Inburi)	1	1.92
13	0.438	CS55	Chansen	1	1.92
Total				52	100

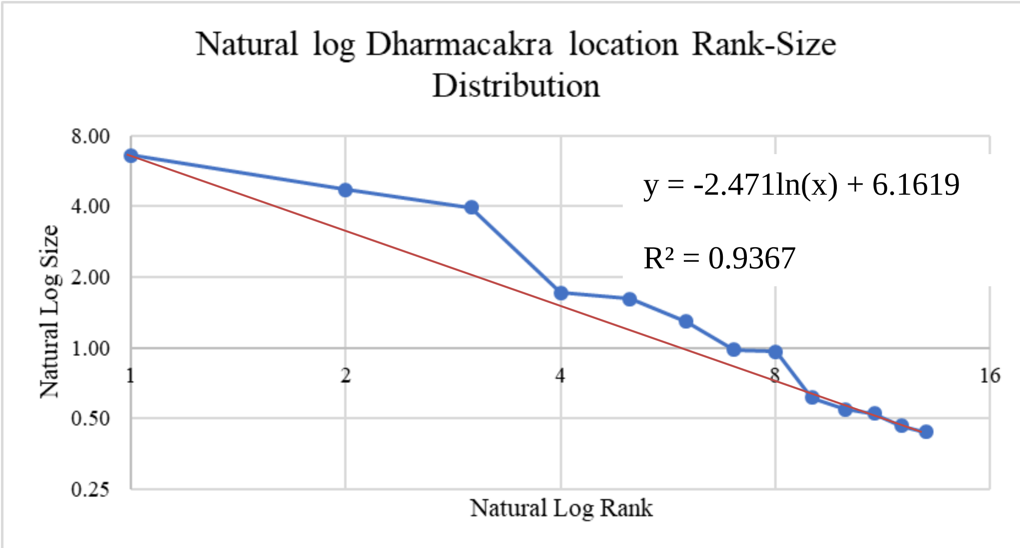
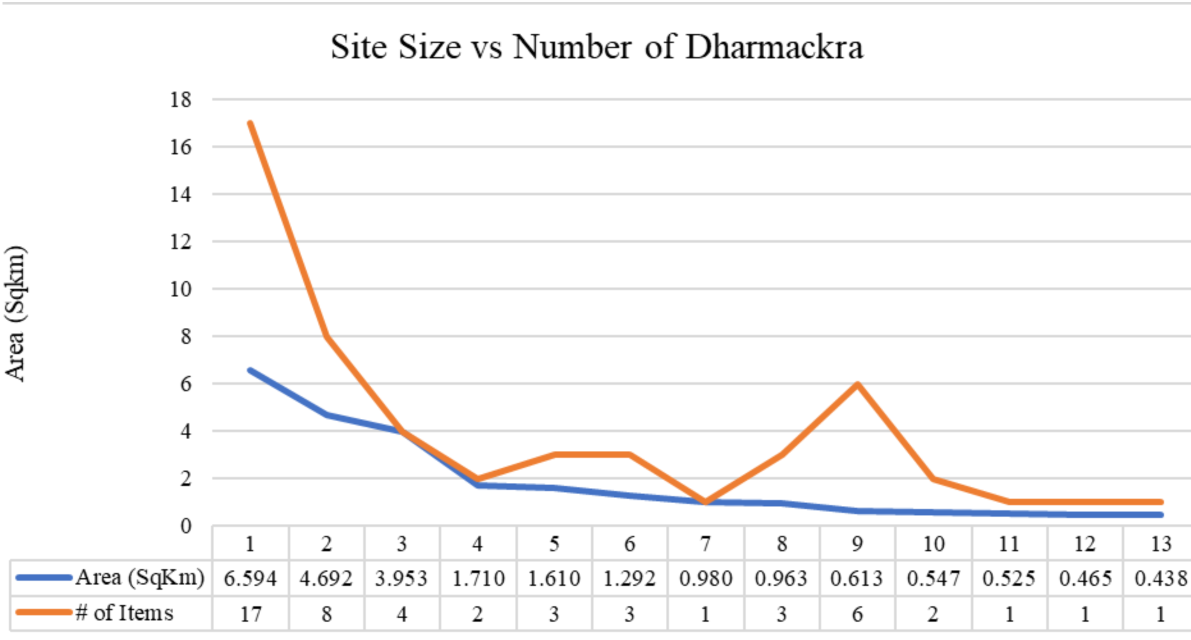


Figure 4.41: Natural log of Dharmacakra sites' rank-size distributions

4.4 Relationship between Dvāravatī Settlements and Dharmacakra Locations

4.4.1 Site Size and Number of Dharmacakras

Presently, there are 13 moated sites in which 52 Dharmacakras were found (Table 4.6 and Figure 4.42). The linear regression is used to test the relationship between site-sizes and number of Dharmacakras. The result shows very strong to perfect association (correlation coefficient (r) =0.87 which is between 0.8 to 1.0) (Caldwell 2009:289) (Figure 4.43). The larger site contains higher number of Dharmacakras. This study shows that Nakhon Pathom is the largest moated site and contains the greatest number of Dharmacakras, the second largest moated site is Si Thep which found the second largest number of items. However, it should be stated that there are some sites reported in which Dharmacakras were found in the literatures, but the current locations of these items could not be identified. In the further research, when additional data on Dharmacakra locations are applied, the analysis result may be altered.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Area (SqKm)	6.594	4.692	3.953	1.710	1.610	1.292	0.980	0.963	0.613	0.547	0.525	0.465	0.438
# of Items	17	8	4	2	3	3	1	3	6	2	1	1	1

Figure 4.42: Graphs show number of Dharmacakra and areas of 13 moated sites

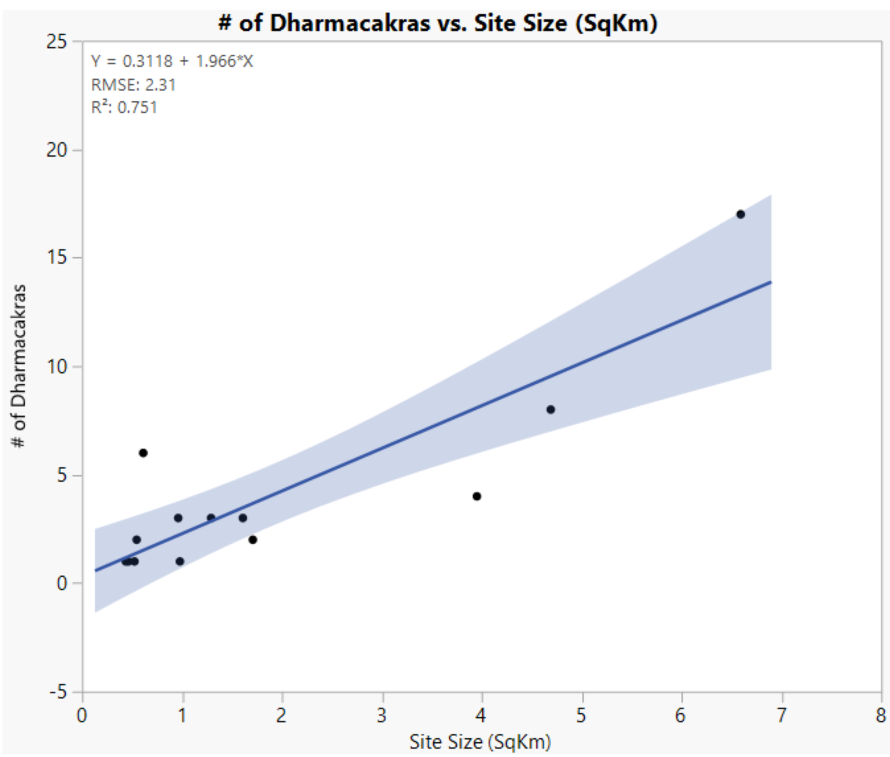


Figure 4.43: Graph and statistical results show strong relationship between site size and number of Dharmacakra (r=8.87)

The KDE is performed to better understand the density of Dharmacakras among those moated sites. The KDE result confirms the greatest density of Dharmacakras at Nakhon Pathom. The second greatest density is found around Pasak river basin which covers Si Thep and Sab Champa which seems to connect with Muang Sema on the east. Another density area is existed around the Upper Central Chao Phraya River basin, around Lop Buri and expand northwestward to U Tapao (Figure 4.44).

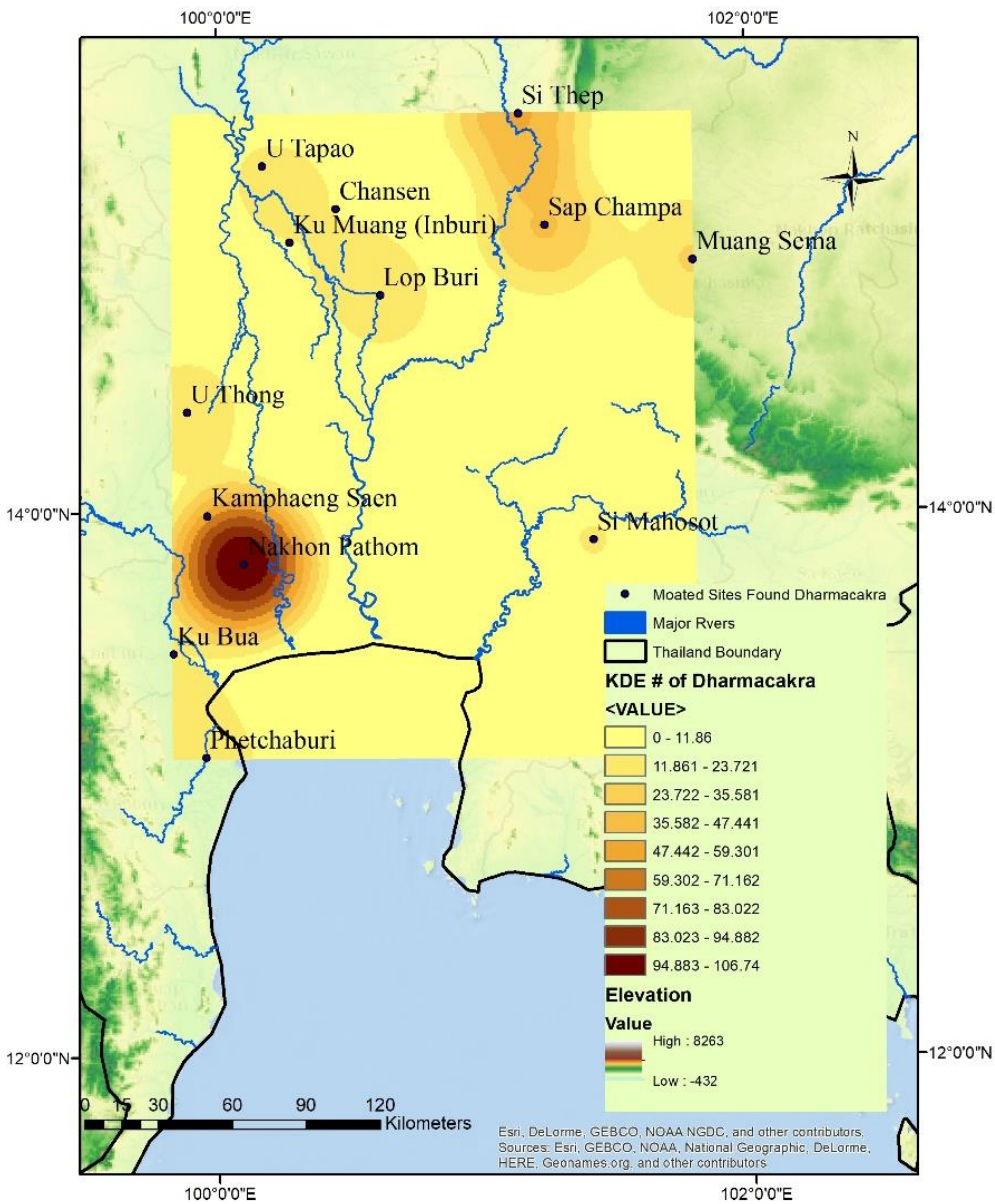


Figure 4.44: The density Dharmacakras in each 13-moated site, map by Areerut Patnukao, basemap from Esri and other contributors

Afterward, the NNA is employed to examine the spatial distribution of these moated sites. The result shows a dispersed pattern of 13 moated sites in which Dharmacakras were found. The Observed Mean Distance is equal to 44273.2327 m, the Expected Mean Distance is 31517.7241 m which gives the Nearest Neighbor Ratio equal to 1.404709, z-score = 2.791551, and p-value = 0.005246 (Figure 4.45).

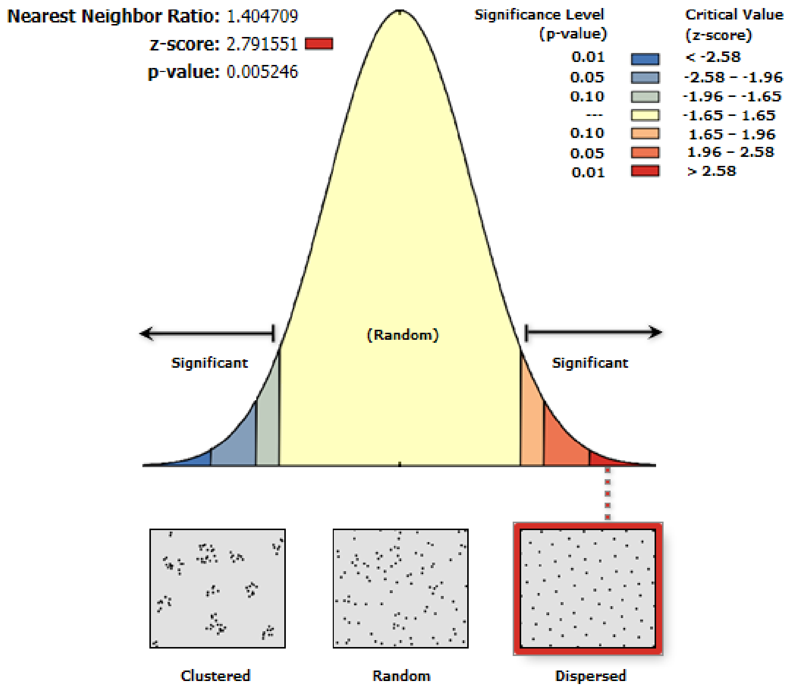


Figure 4.45: Normal distribution curves showing nearest neighbor statistics and dispersed pattern of 13 moated sites in which Dharmacakras were found

4.4.2 Dharmacakra as the Symbol of Regional Center or Boundary Marker

The spatial pattern of the 13 moated sites in which 52 Dharmacakras were found is dispersed. The additional function of these Dharmacakra sites are tested whether they can indicate the regional centers or the boundary of the kingdom or not. Presumably, if there is a positive relationship between the number of Dharmacakras and number of sites around them. Consequently, Dvāravatī site which has more number of Dharmacakras should have higher number of sites surrounded it. The proportions of three different categories of sites, including all site types

(425 sites), Ancient Town and Ancient Community site types (139 sites), and moated sites (59 sites) within a buffer of 22.5 km from 13 Dharmacakra sites were analyzed. A buffer of 22.5 km, which is equal to half of distance of the observed mean nearest distance (~45 km) of 13 Dharmacakra sites, is chosen to find the quantity of sites surrounded Dharmacakra sites.

Afterward, Chi-Square is used to test the relationships between: Dharmacakra-site area and number of sites around them; and the number of Dharmacakras and number of sites surrounded them. The results show no significant relationship between these variables (Tables 4.7 and 4.8). Additionally, the linear regression is used to test the relationships between these variables. The results range from negative moderate to positive moderate associations between these variables (Tables 4.7, 4.8 and Figure 4.46). The histograms are used to spatially visualize the comparison of number of sites that surrounded Dharmacakra sites in three different site categories (Figure 4.47). Nakhon Pathom has both the largest area and highest number of Dharmacakra as well as the highest number of sites from all site types around it. Si Thep is the second largest in term of area and number of Dharmacakras, but has very few numbers of sites around it. U Tapao is fairly small but it has the highest number of Ancient Town and Ancient Community sites as well as moated sites around it.

Currently, neither number of Dharmacakras nor their locations within the same site are adequate to indicate the regional centers or the boundary of Dvāravatī culture. However, it should be noted that the number of Dharmacakras relate to the size of sites which may emphasize an importance of those sites in which Dharmacakras were found. Moreover, since the origins of Dharmacakra locations are not so accurate, the result may be altered if there are additional data available or unearthing more Dharmacakras in the future. In further research, the spatial distribution of other art materials or buildings should be incorporated to analyze the geographic boundary and centers of Dvāravatī culture.

Table 4.7: The results from statistical analyses between number of Dharmacakras and proportions of surrounded sites in three different site categories

X (Factor)	**Y (Response)**	**χ^2**			**Linear Regression**	
		N	**χ^2**	**Prob> χ^2**	**R**	**Association**
# of Dharmacakra	# of site from all site types (425)	13	65	0.3068	+0.462	Moderate
# of Dharmacakra	# of site from AC and AT sites (139)	13	40.444	0.7724	-0.476	Moderate
# of Dharmacakra	# of site from moated sites (59)	13	9.75	0.9398	-0.321	Weak

Table 4.8: The results from statistical analyses between Dharmacakra-site sizes and proportions of surrounded sites in three different site categories

X (Factor)	**Y (Response)**	**χ^2**			**Linear Regression**	
		N	**χ^2**	**Prob> χ^2**	**R**	**Association**
Site Size (km)	# of site from all site types (425)	13	130	0.2511	+0.475	Moderate
Site Size (km)	# of site from AC and AT sites (139)	13	104	0.271	-0.518	Moderate
Site Size (km)	# of site from moated sites (59)	13	39	0.3364	-0.386	Weak

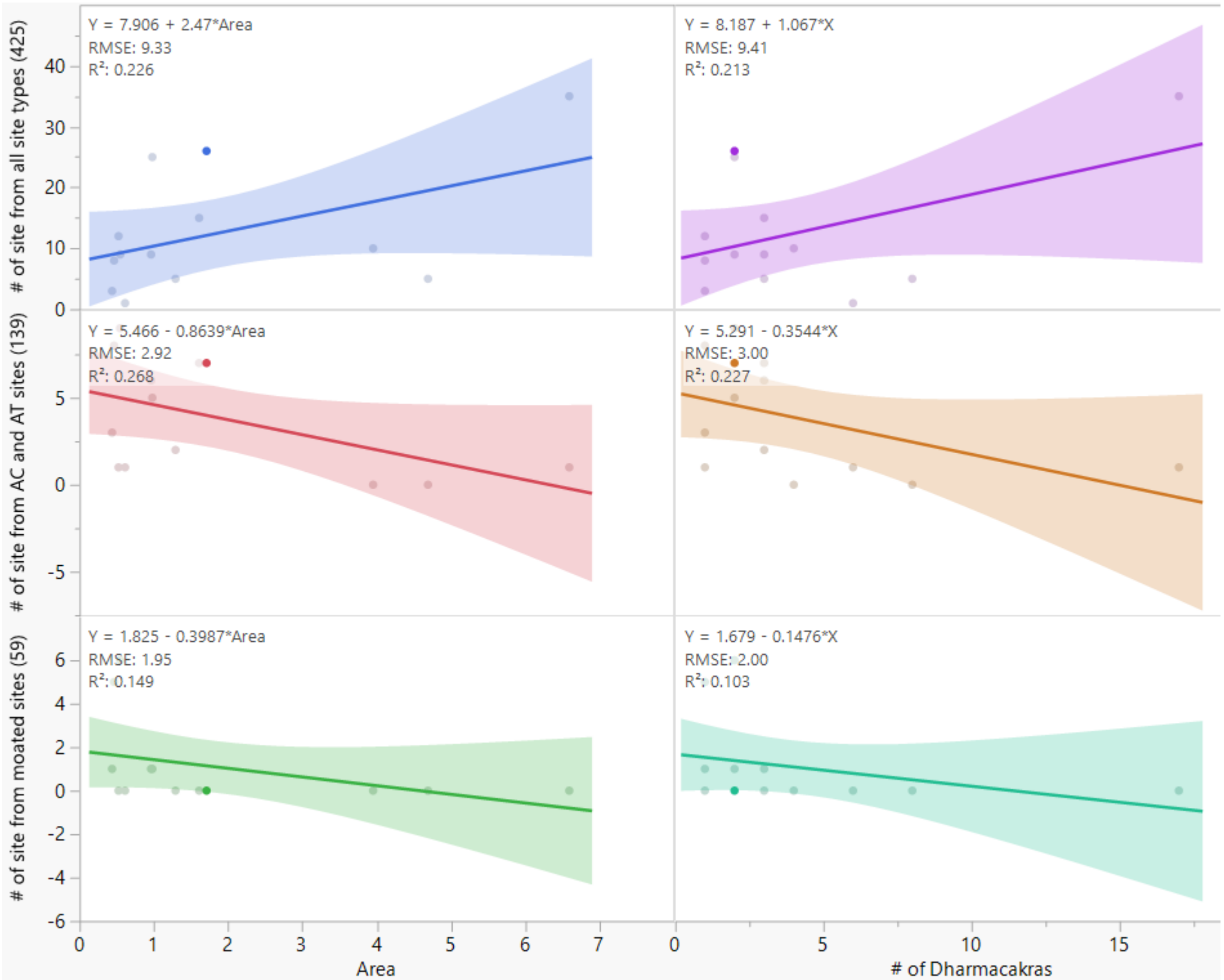
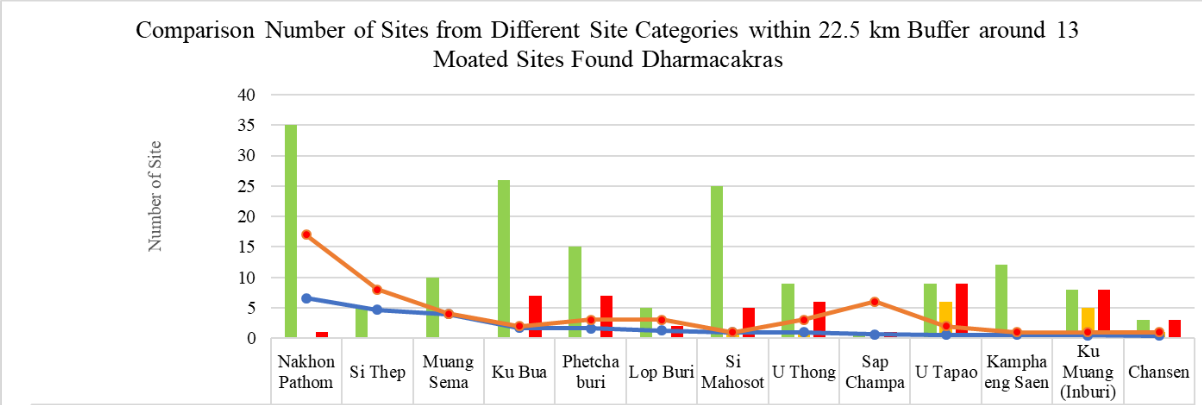


Figure 4.46: Graphs and statistical results showing degrees of association between Dharmacakra-site areas and different types of sites surrounded them (Left) and between number of Dharmacakras and different types of sites surrounded them (Right)



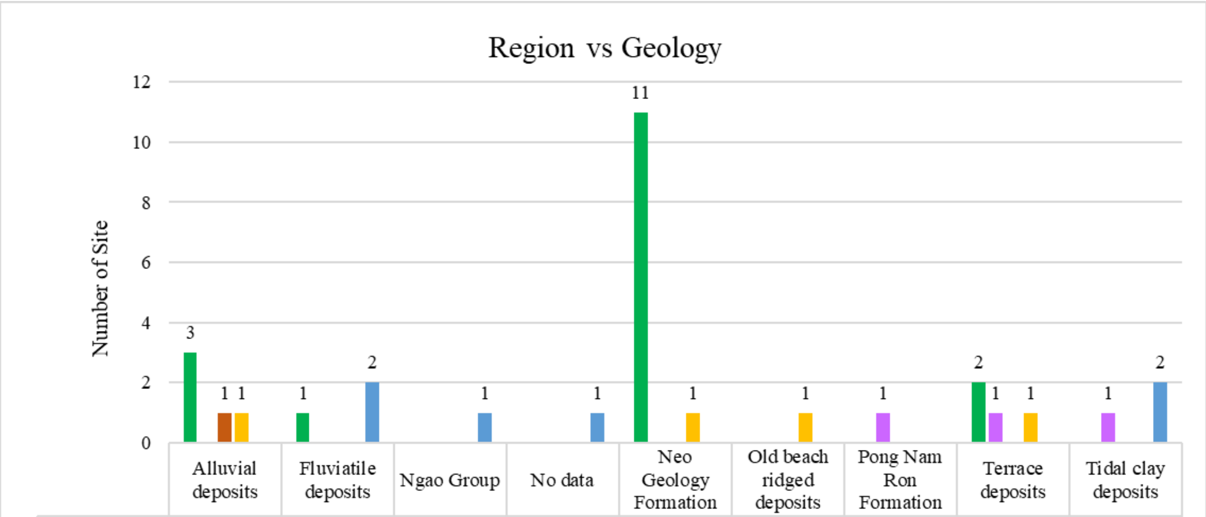
	Nakhon Pathom	Si Thep	Muang Sema	Ku Bua	Phetcha buri	Lop Buri	Si Mahosot	U Thong	Sap Champa	U Tapao	Kampha eng Saen	Ku Muang (Inburi)	Chansen
from 425 sites	35	5	10	26	15	5	25	9	1	9	12	8	3
from 59 moated sites	0	0	0	0	0	0	1	1	0	6	0	5	1
from 139 AC and AT sites	1	0	0	7	7	2	5	6	1	9	1	8	3
Area (SqKm)	6.594	4.692	3.953	1.71	1.61	1.292	0.98	0.963	0.613	0.547	0.525	0.465	0.438
# of Dharmacakra	17	8	4	2	3	3	1	3	6	2	1	1	1

Figure 4.47: The comparison number of sites in three different categories that surrounded Dharmacakra sites within 22.5 km buffer

4.4.3 Dharmacakra Locations and Spatial Variables

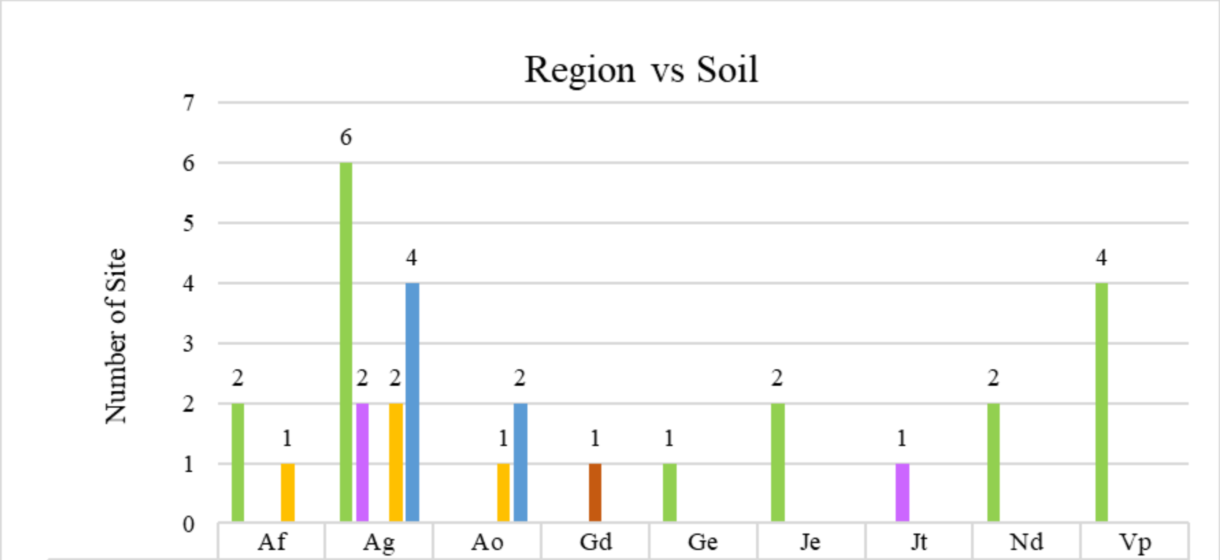
Overall, there are currently 31 sites in which Dharmacakras were found. There are only five regions, except northern region, that have been found the Dharmacakras. Almost 39% of sites are located in Neo Geology Formation. 16% of sites are located in Alluvial deposits. These deposits are found in Central Plain, Southern, and Northeastern regions. Almost 13% of sites are located in Terrace deposits. The Dharmacakra sites in Western region are located mostly in Fluviatile and Tidal clay deposits. The sites in Eastern region are located in Pong Nam Ron formation, terrace and tidal clay deposits (Figure 4.48).

The majority of sites (45.16%) are located in Gleyic Acrisols (Ag) which are suitable for growing rice. A site in Northeastern region is located in Dystric Gleysols (Gd) which occur mainly in Mun and Chi river basins. They are developed on riverine alluvium and occupy on low river terraces (Figure 4.49). Most of sites in Chao Phraya basin are located in Pellic Vertisols (Vp) which occur where a distinct monsoon climate exists. Majority of sites in Pa Sak basin are located in Dystric Nitosols (Nd) which developed on various highly weathered rocks and sediments and have a nearly level to hilly macrorelief (Figure 4.50). Most of Dharmacakra sites in all regions and river basins are located below 50 m MSL (Figure 4.51).



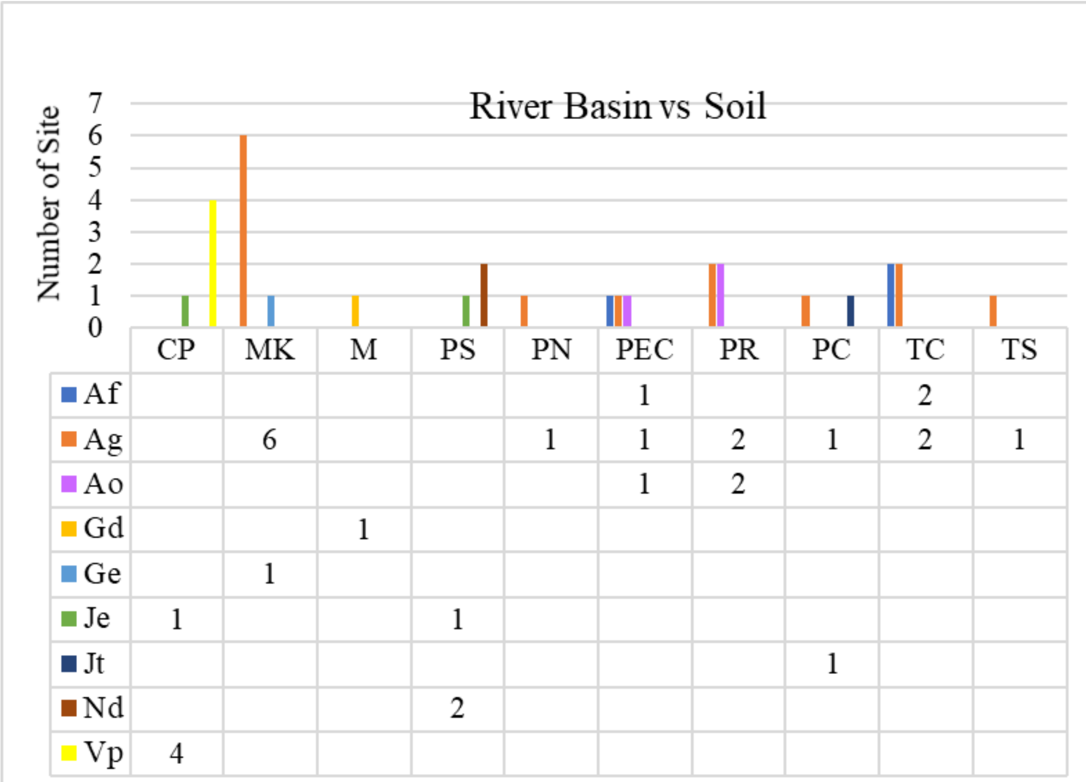
	Alluvial deposits	Fluviatile deposits	Ngao Group	No data	Neo Geology Formation	Old beach ridged deposits	Pong Nam Ron Formation	Terrace deposits	Tidal clay deposits
Central Plain	3	1			11			2	
East							1	1	1
Northeast	1								
South	1				1	1		1	
West		2	1	1					2

Figure 4.48: A histogram shows number of Dharmacakra sites by geology types in each region



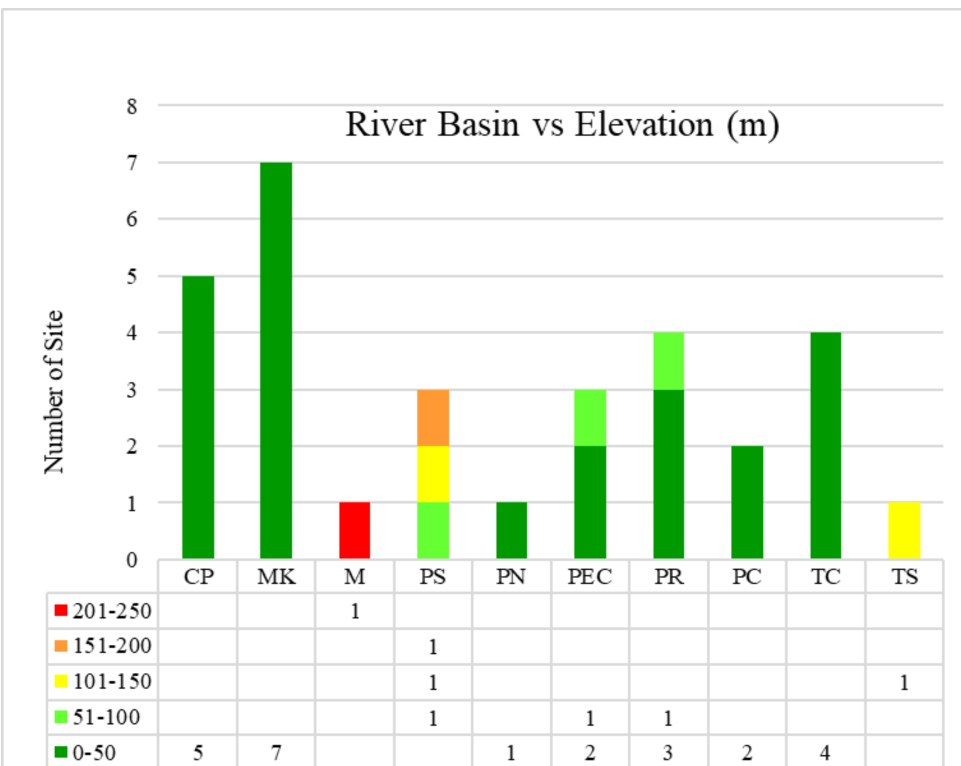
	Af	Ag	Ao	Gd	Ge	Je	Jt	Nd	Vp
Central Plain	2	6			1	2		2	4
East		2					1		
Northeast				1					
South	1	2	1						
West		4	2						

Figure 4.49: A histogram shows number of Dharmacakra sites by soil types in each region



	CP	MK	M	PS	PN	PEC	PR	PC	TC	TS
Af						1			2	
Ag		6			1	1	2	1	2	1
Ao						1	2			
Gd			1							
Ge		1								
Je	1			1						
Jt								1		
Nd				2						
Vp	4									

Figure 4.50: A histogram shows number of Dharmacakra sites by soil types in each river basin



	CP	MK	M	PS	PN	PEC	PR	PC	TC	TS
201-250			1							
151-200				1						
101-150				1						1
51-100				1		1	1			
0-50	5	7			1	2	3	2	4	

Figure 4.51: A histogram shows number of Dharmacakra sites by elevation in each river basin

Proximity Distance to Access Water Source

Table 4.9 presents data on Dharmacakra site location by distance closest to water source in relation to region. There are 8 sites (25.81%) that can access to water resource within 1 km. All sites are located within 20 km to water source. The Central Plain has the most variety of distances to access water resource which positively relates to the number of Dharmacakra sites (Figure 4.52).

Table 4.9: Dharmacakra site location by distance closest to water source in relation to region

Distance to Closest River (km)	**Region**						
	Central Plain	**East**	**Northeast**	**South**	**West**	**Total**	**%**
1	3	1		2	2	8	**25.81**
2	1			1		2	**6.45**
5	2		1		2	5	**16.13**
10	3	1		1	2	7	**22.58**
15	5	1				6	**19.35**
20	3					3	**9.68**
Total	**17**	**3**	**1**	**4**	**6**	**31**	**100**

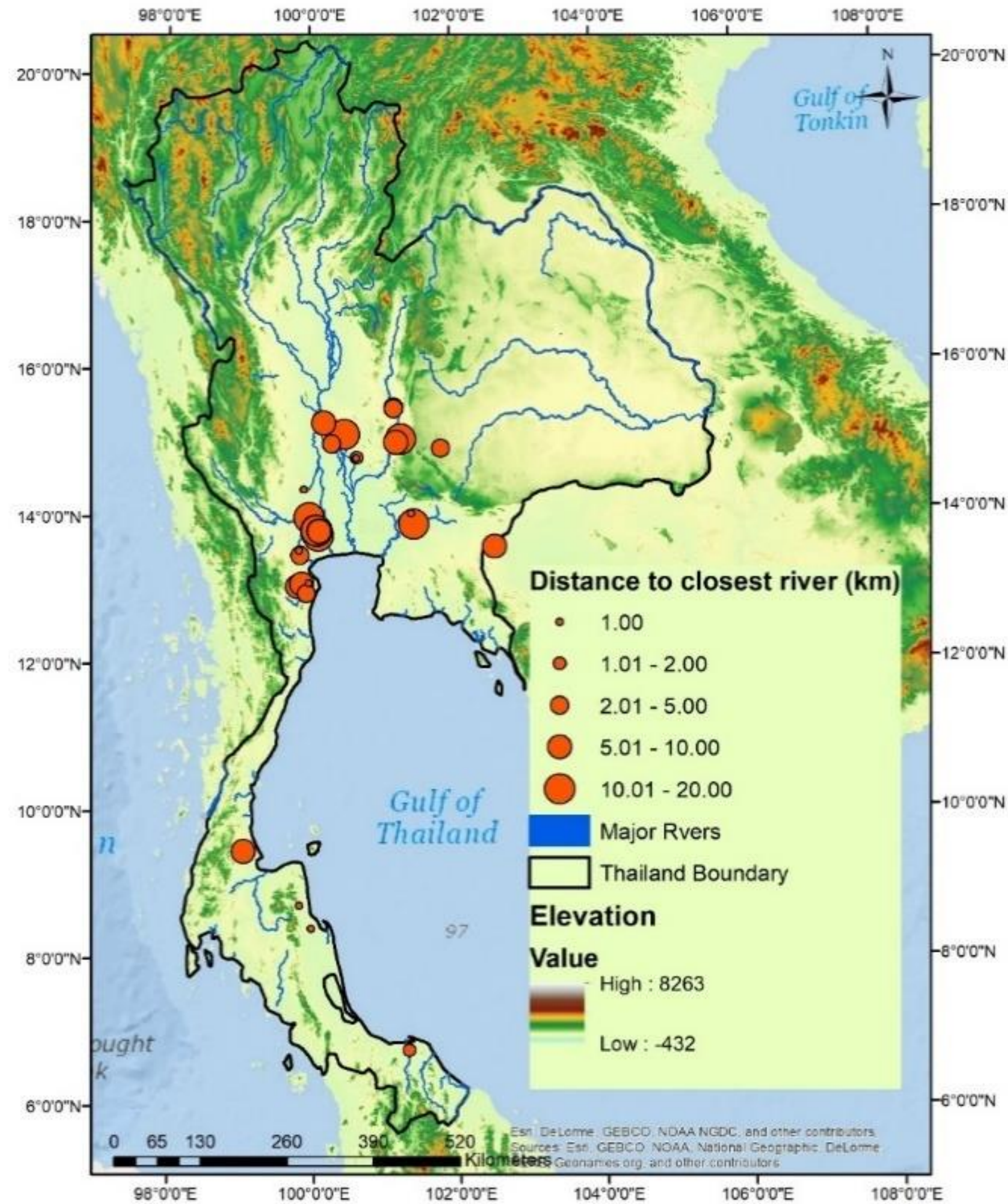


Figure 4.52: The distribution of Dharmacakra sites to the closest water source, map by Areerut Patnukao, basemap from Esri and other contributors

4.5 Relationship between Dharmacakra Locations and Art-Style Variables

Over 93 % of Dharmacakras are made from stones which roughly include argillite, sand stone, laterite, and slate. The rest is made from terra-cotta. The further research should be done on material analysis to trace the potential sources of the materials and to better understand how Dvāravatī people used the resources. The height of completed stone Dharmacakras ranges from 70 cm up to 219 cm and the diameters range from 70 cm to 200 cm. 76 % of Dharmacakra spokes are not cut through. Number of spoke varies from 8 to 36 and 16 spokes are the most frequent numbers (Appendix B Table B.2 and B.3). It should be noted that there are eight sites (CS81, CS85, CS86, CS88, ES37, WS10, WS12, and WS25) which are mentioned in literatures that found Dharmacakras, but could not presently locate Dharmacakra items neither from field survey nor from previous studies (Figure 4.53). In addition, there are four Dharmacakras (NMC1, NMC4, NMC14, and NMC18) that could not identify the original locations.

The analysis of Dharmacakra location and its motif or art-style variables is a necessary step in understanding the relationship between them. In this study, Brown's (1996) and Indorf's (2014) index chronologies were used to classify Dharmacakras (see Appendix B, table B.2). Brown (1996) grouped the 42 Dharmacakras into 6 groups based on an analysis of patterns; 1) lozenge-and-circle pattern, 2) volutes-and-circle pattern, 3) rinceau pattern, 4) idiosyncratic patterns, 5) plain fellies, and 6) Hindu cakra related types. Indorf (2014) continued Brown's work and classified Dharmacakra into 4 types based on felly and base, namely Funan, Khmer, Mon, and Mon–Khmer mixed styles (see detail in Chapter 2 section 2.2.2).

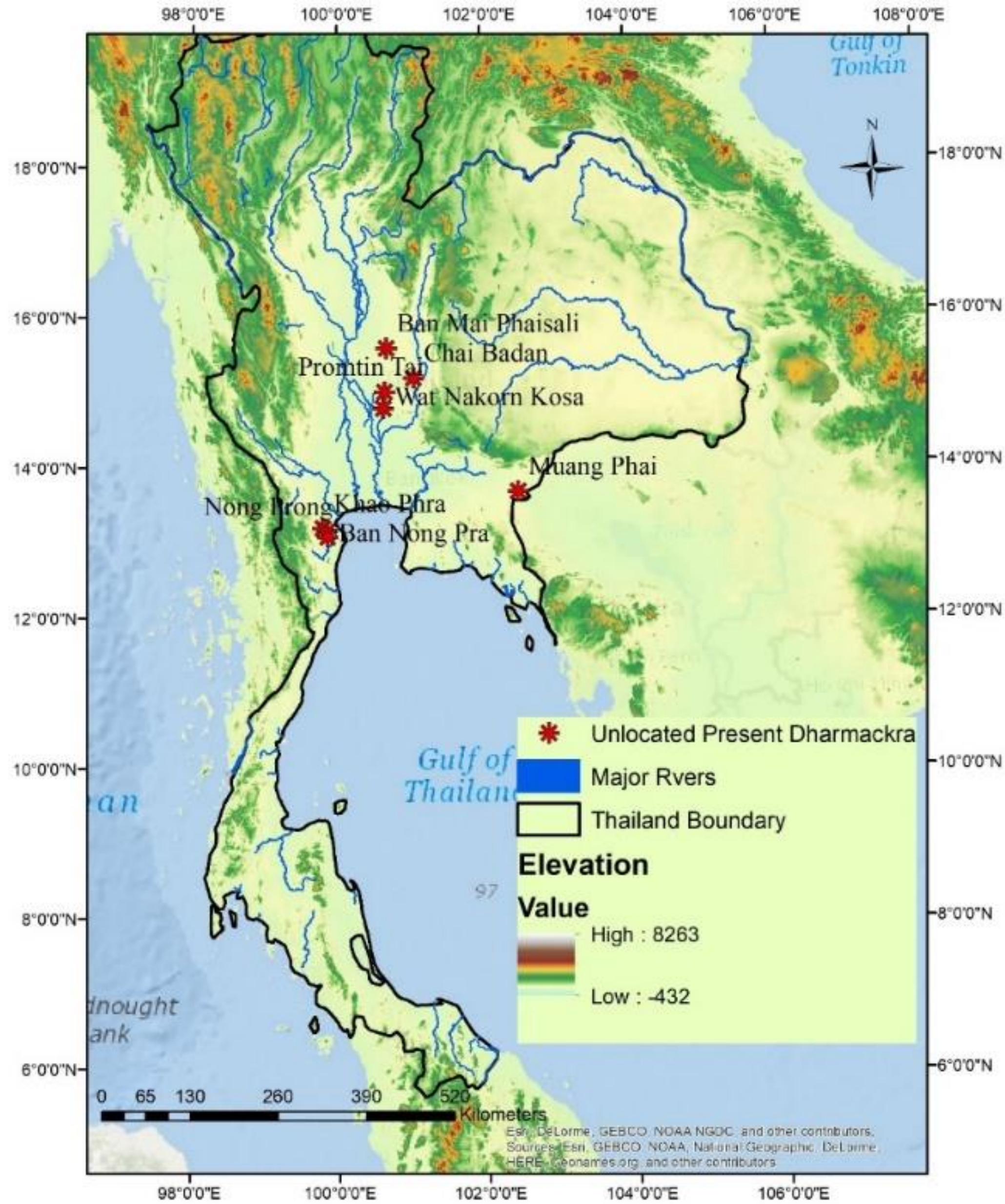


Figure 4.53: Sites that reportedly found Dharmacakras but could not presently locate the items, map by Areerut Patnukao, basemap from Esri and other contributors

27.5 % of Dharmacakra is Khmer style, the second greatest number is Mon style, 26.25%. Mon Funan style has the least number, 7% (Table 4.10 and Figures 4.54 and 4.55). Central Plain has all types of base and felly. Funan style is appeared in Central Plain, Eastern, and Southern regions (Figure 4.56). Khmer style is present mostly at Central Plain, Northeast, and West of Thailand (Figure 4.57). Mon style is found at Central Plain, Southern, and Western regions which geographically relates to Mon culture located in Myanmar (Figure 4.58). Eastern region found only Funan and Mon-Khmer Mixed styles which geographically relates to its neighbor cultures (Figure 4.59). Funan and Khmer cultures are located in the eastern side of Thailand. There are 19 Dharmacakras (23.75%) that have not been identified art styles due to several reasons (Figure 4.60). For instance, some of these Dharmacakras are recently obtained from field survey which have not been studied before. Some of them have missing parts of base and felly which could not be identified. Some of them are not made of stone and have very small size. In the future research, these Dharmacakras art styles should be identified and reanalyzed.

Table 4.10: Number of Dharmacakras in each base and felly type

Indorf's (2014) base and felly Type	**# of Dharmacakras**	**%**
Funan	6	7.5
Khmer	22	27.5
Mon	21	26.25
Mon-Khmer Mixed	12	15
Unidentified	19	23.75
Grand Total	**80**	**100**

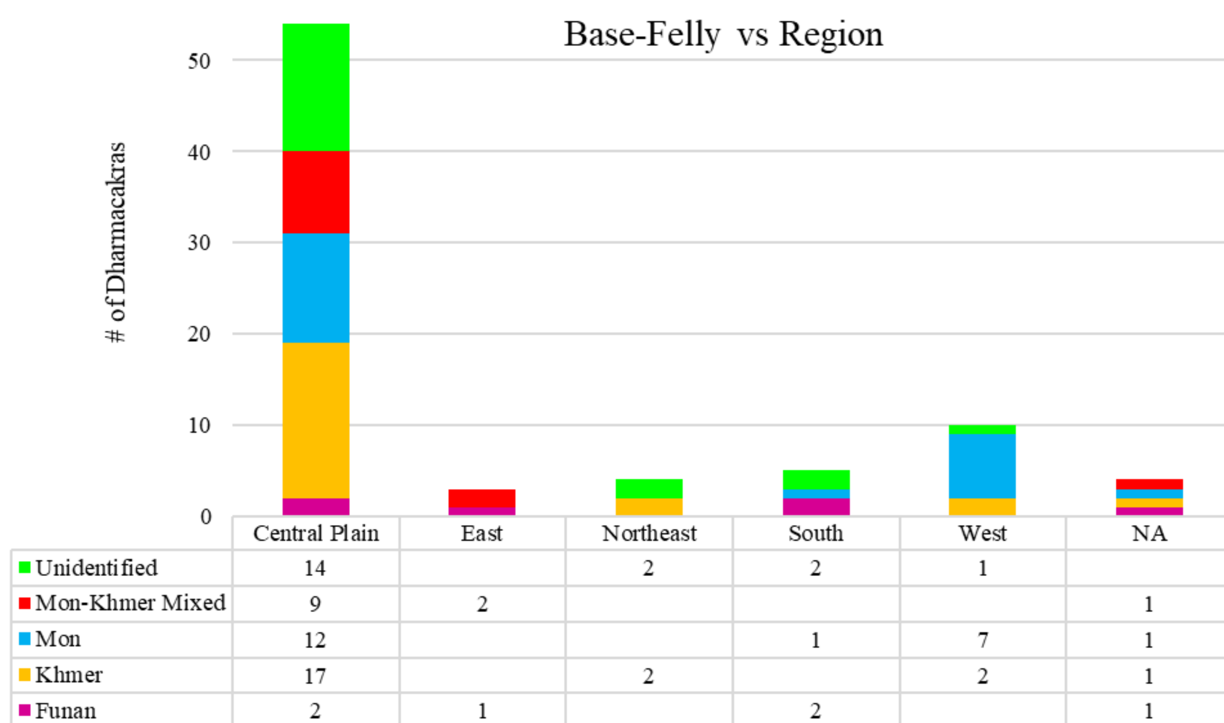


Figure 4.54: Base and felly type in each region

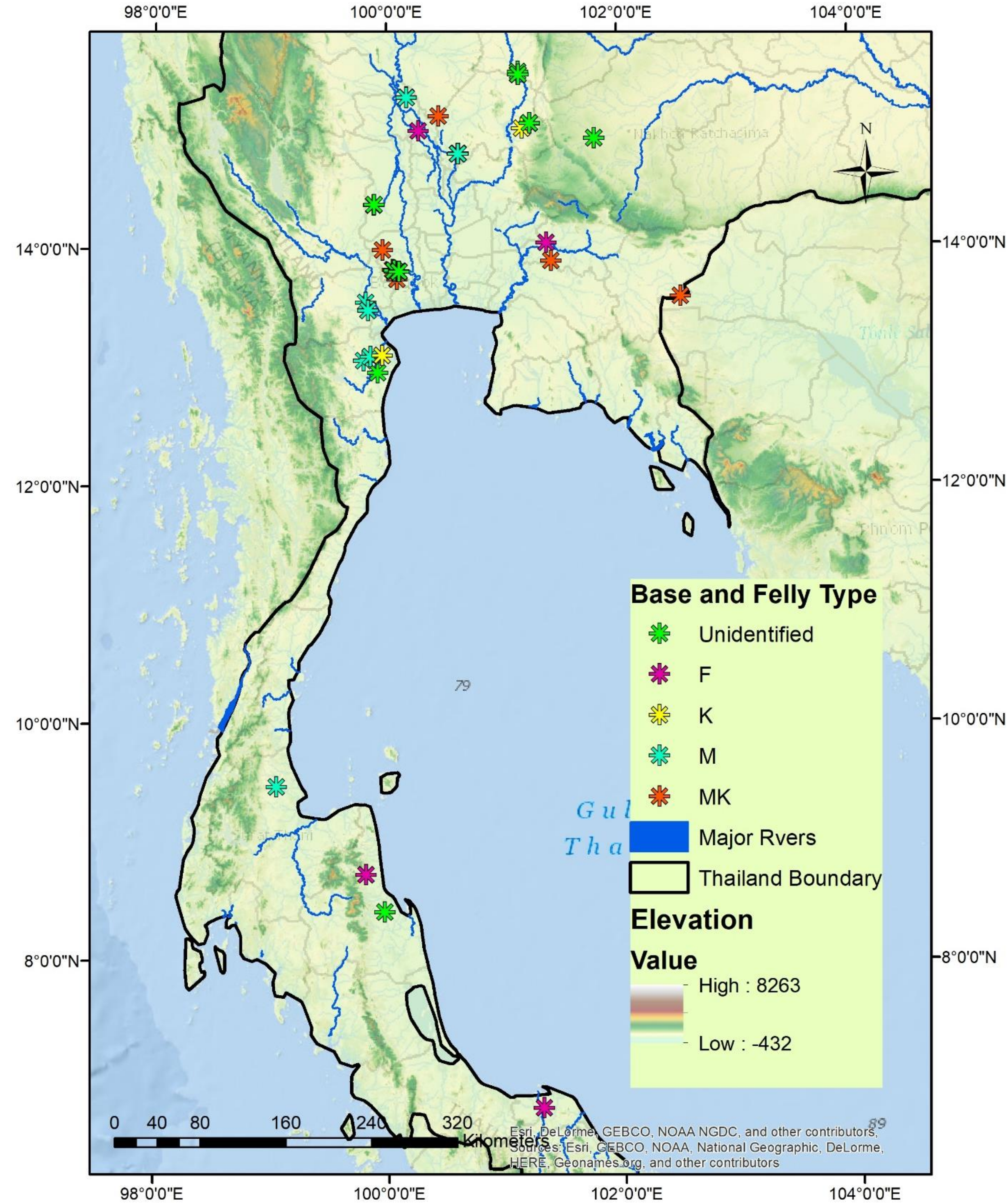


Figure 4.55: Spatial distributions of all base and felly types, map by Areerut Patnukao, basemap from Esri and other contributors

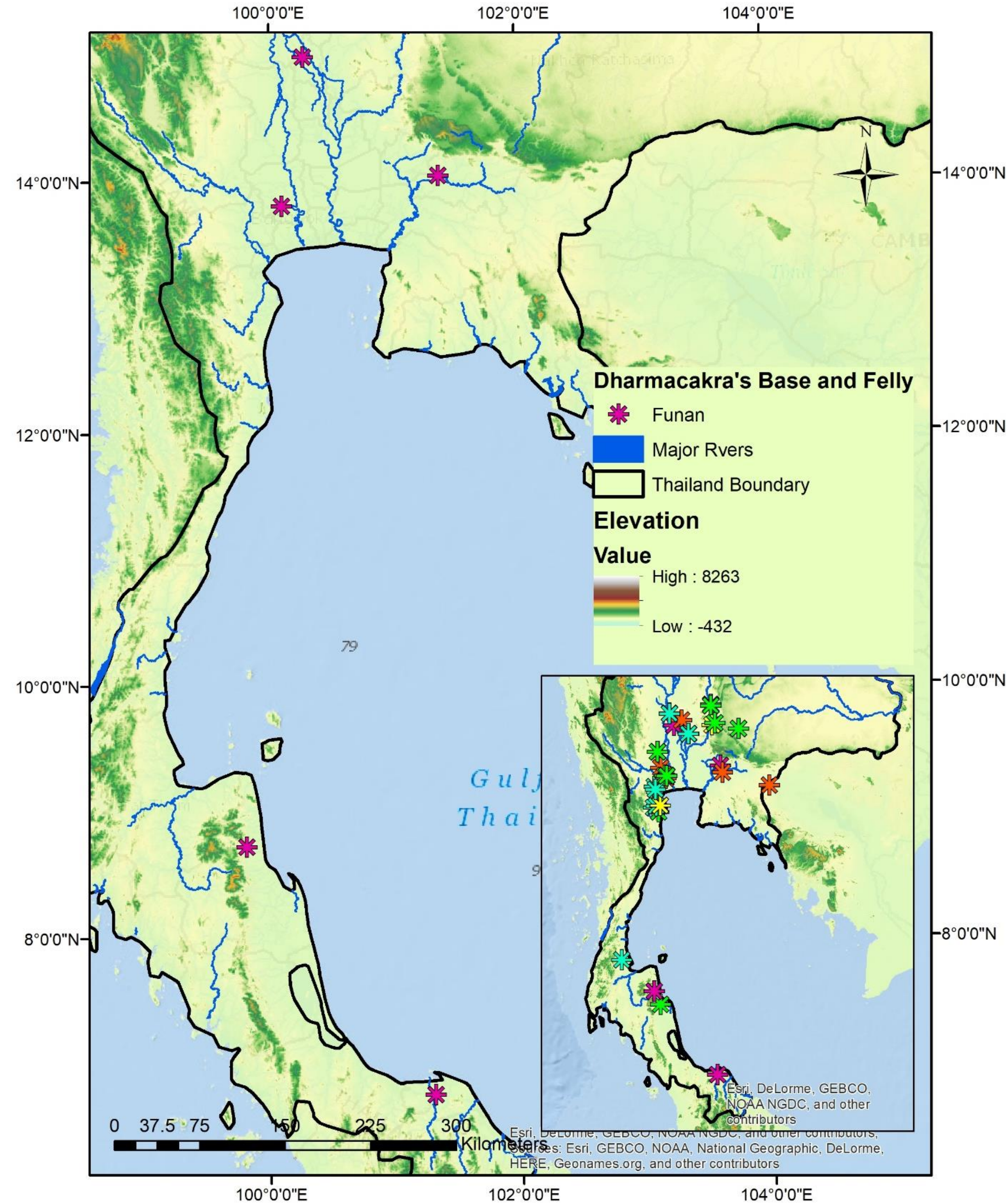


Figure 4.56: Spatial distributions of Funan base and felly type, map by Areerut Patnukao, basemap from Esri and other contributors

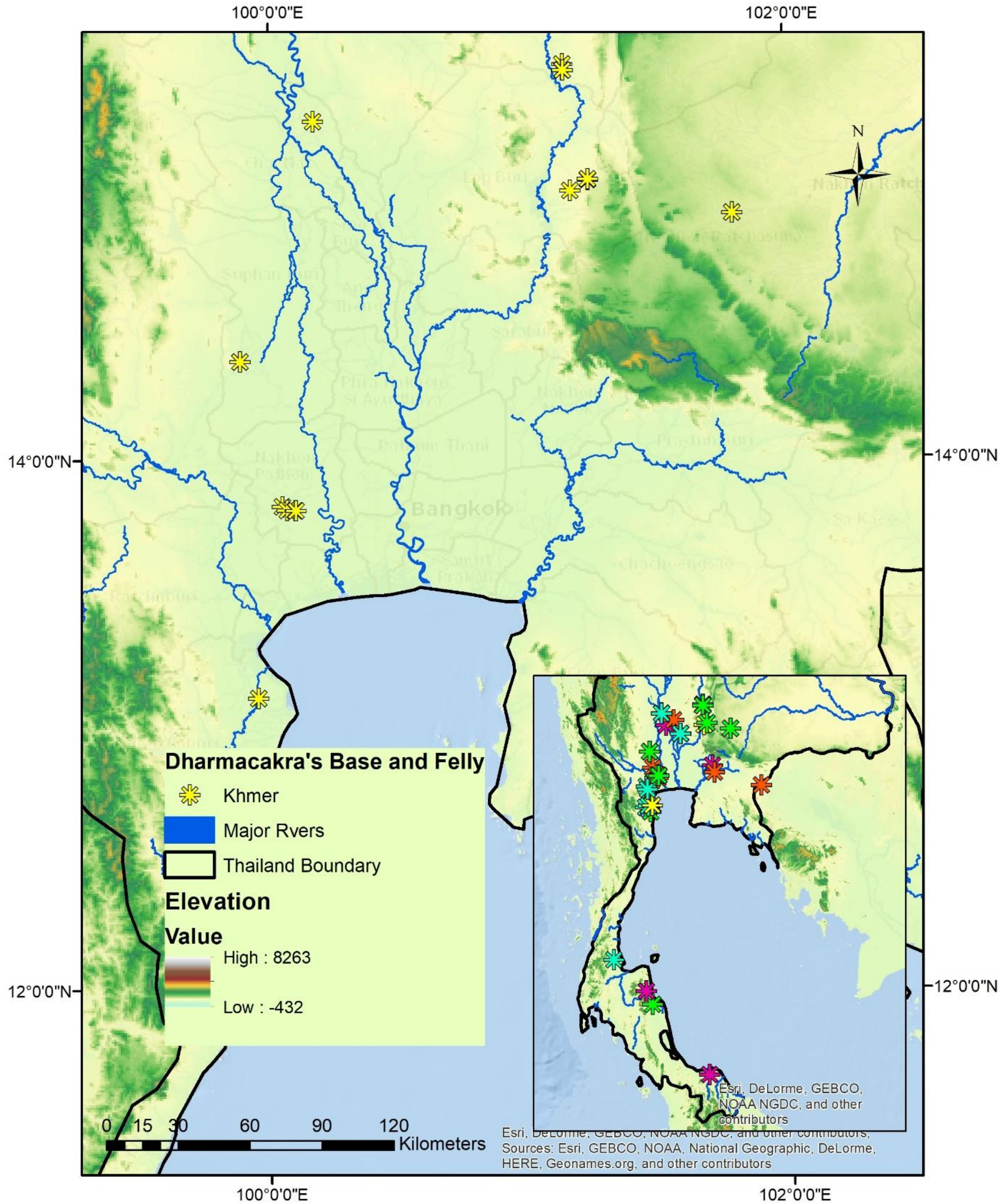


Figure 4.57: Spatial distributions of Khmer base and felly type, map by Areerut Patnukao, basemap from Esri and other contributors

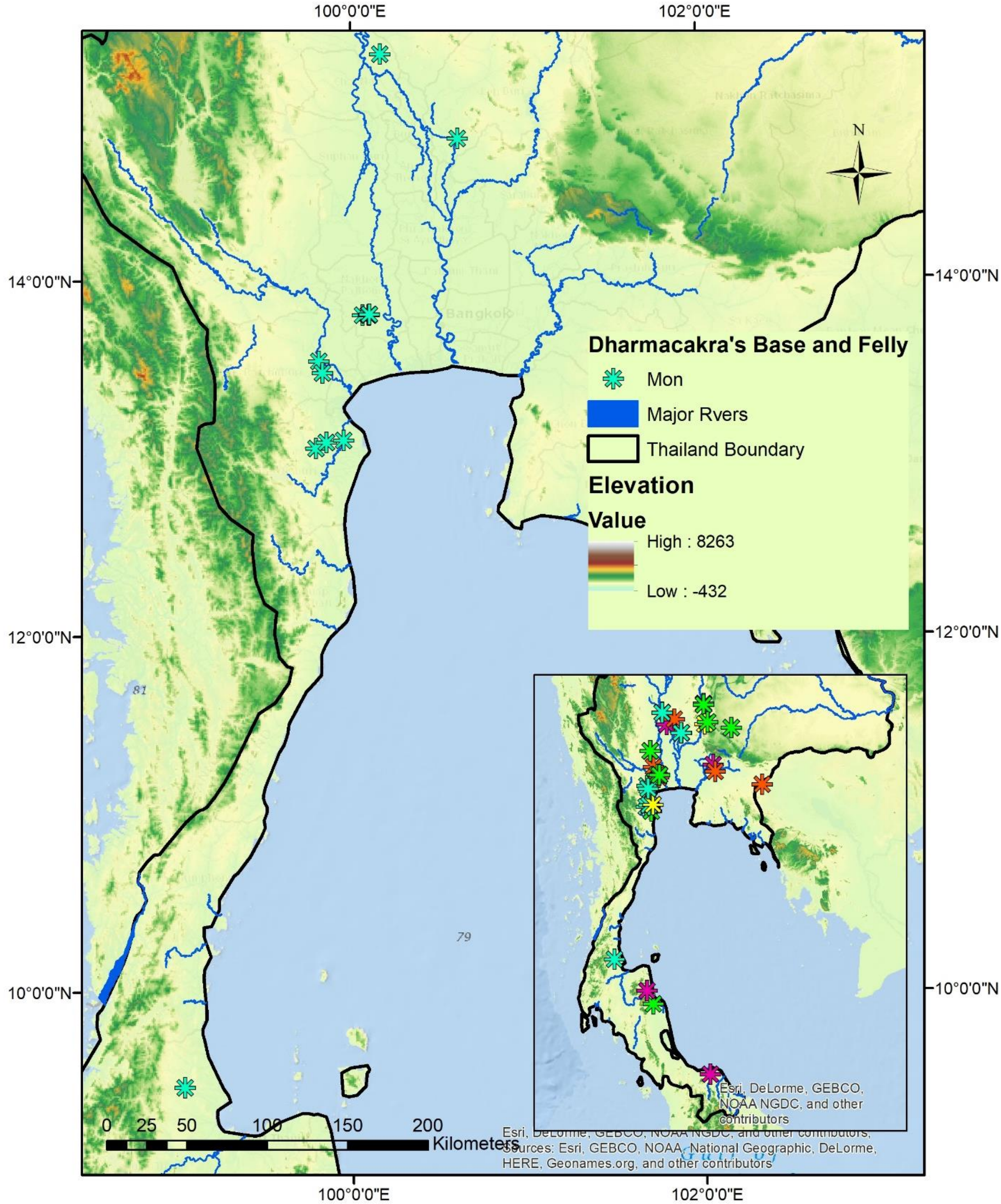


Figure 4.58: Spatial distributions of Mon base and felly type, map by Areerut Patnukao, basemap from Esri and other contributors

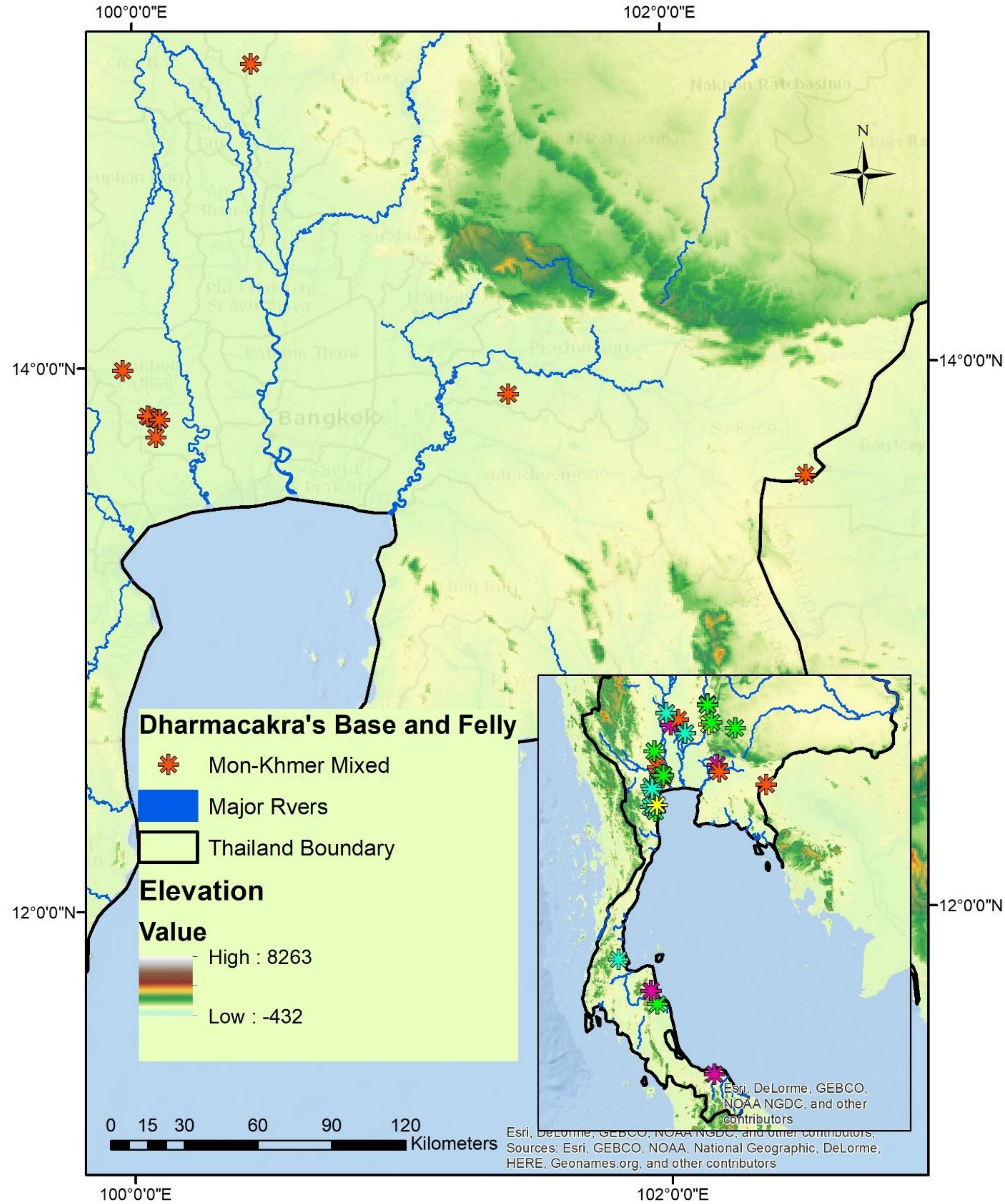


Figure 4.59: Spatial distributions of Mon-Khmer Mixed base and felly type, map by Areerut Patnukao, basemap from Esri and other contributors

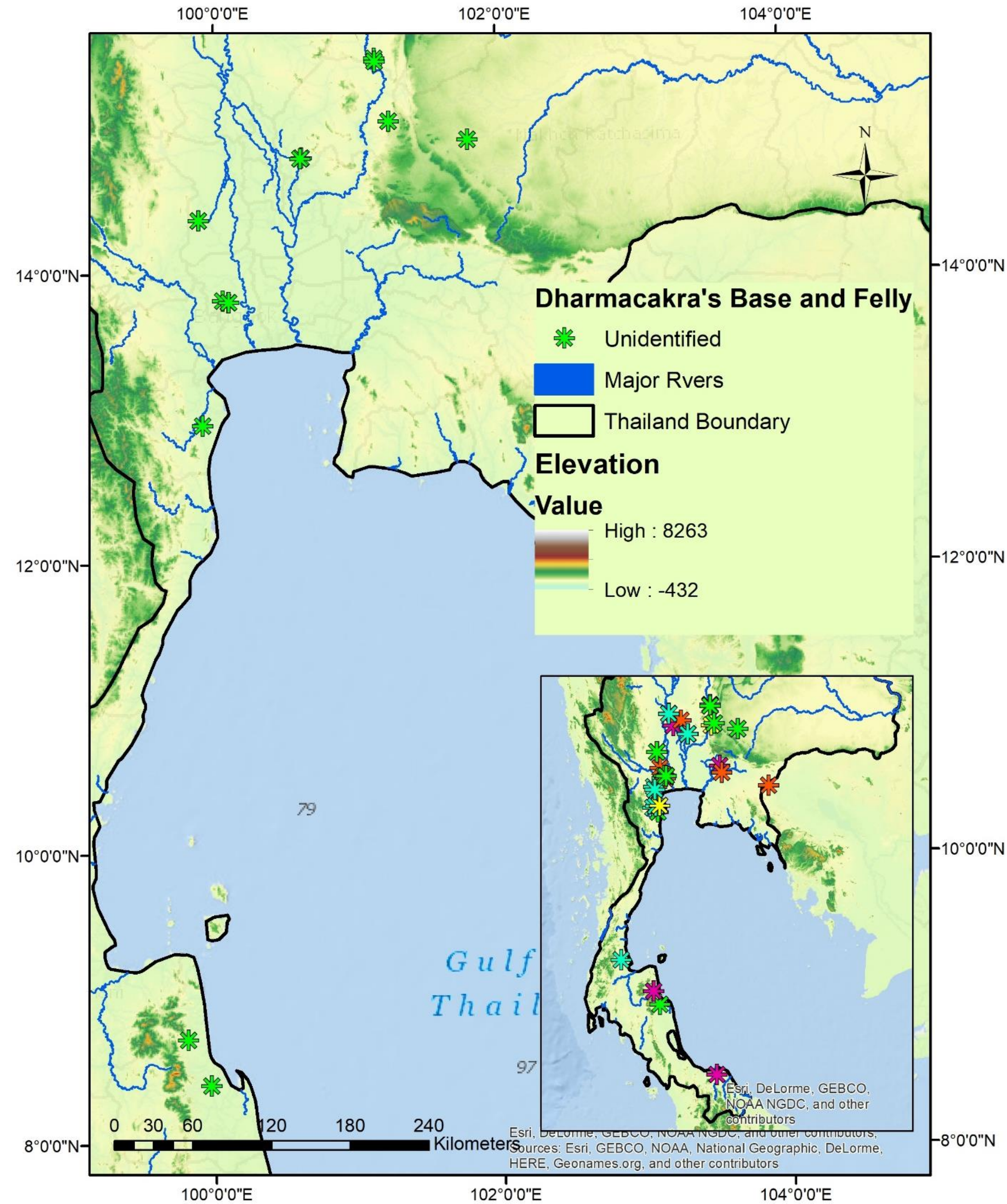
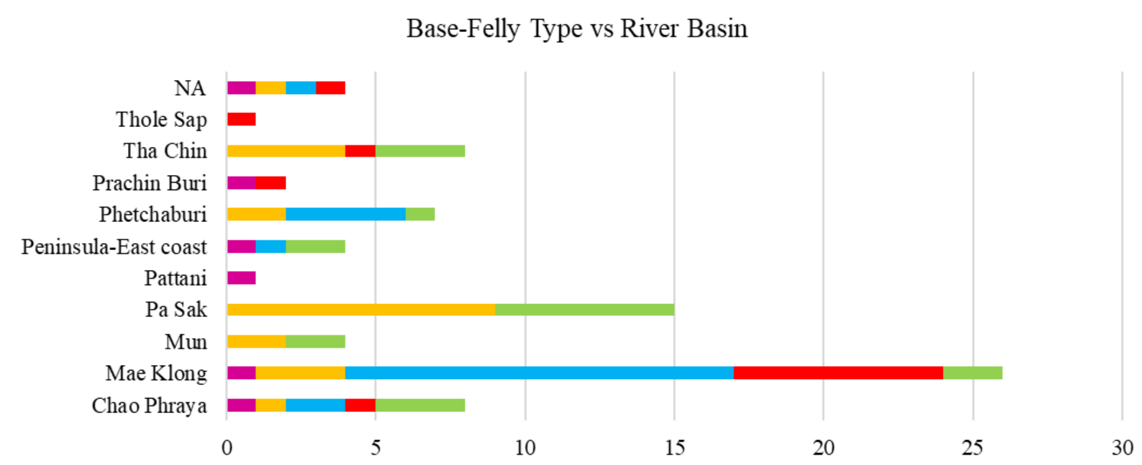


Figure 4.60: Spatial distributions of unidentified style, map by Areerut Patnukao, basemap from Esri and other contributors

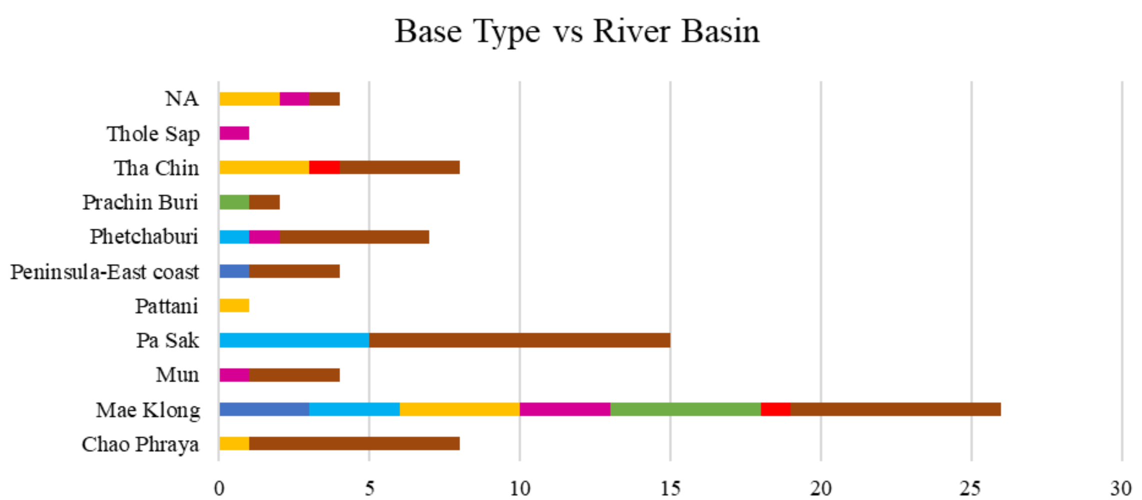
In addition, base and felly types geographically relate to their river basins. Mae Klong river basin has the greatest number of Dharmacakras and has all base and felly types. Khmer style is found mostly in Pa Sak river basin. Mon and Mon-Khmer Mixed styles are occurred mostly in Mae Klong basin. Funan is shown in very small number and does not specify in any certain river basin (Figure 4.61).

Every base type is also existed only in Mae Klong basin. 2B-base type (a figure of Sūrya or a Kala face) is the most found in river basins, 4 basins. Dharmacakras with 1B-base type have the greatest number in Pa Sak basin. Dharmacakras with 2A-base type (a tapered or triangulated flame column) are appeared in the greatest number at Tha Chin basin. Dharmacakras with 1A-base type (with a lotus below the felly), 1C-base type (with only a raised rectangle on the felly), 2B-base type (a figure of Sūrya or a Kala face), and 3A-base type (non-figural, floral *śrī* stele) are found the highest number in Ma Klong river basin. Dharmacakras with 3B-base type (with figure) are found only at Mae Klong and Tha Chin basins with very few number, one each (Figure 4.62).



	Chao Phraya	Mae Klong	Mun	Pa Sak	Pattani	Peninsula-East coast	Phetchaburi	Prachin Buri	Tha Chin	Thole Sap	NA
Funan	1	1			1	1		1			1
Khmer	1	3	2	9			2		4		1
Mon	2	13				1	4				1
Mon-Khmer Mixed	1	7						1	1	1	1
Unidentified	3	2	2	6		2	1		3		

Figure 4.61: Base and felly type in each river basin

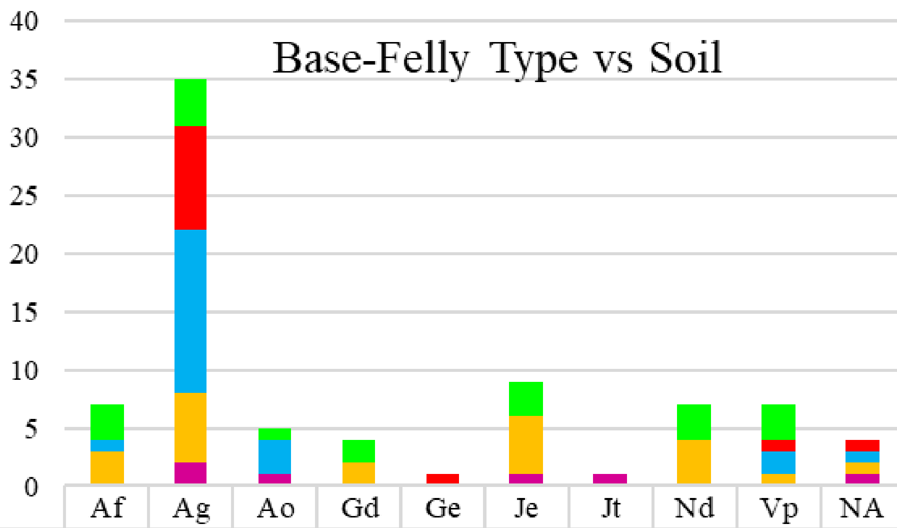


	Chao Phraya	Mae Klong	Mun	Pa Sak	Pattani	Peninsula-East coast	Phetchaburi	Prachin Buri	Tha Chin	Thole Sap	NA
1A		3				1					
1B		3		5			1				
1C		3			1						
2A	1	1							3		2
2B		3	1				1			1	1
3A		5						1			
3B		1							1		
Unidentified	7	7	3	10		3	5	1	4		1

Figure 4.62: Base type in each river basin

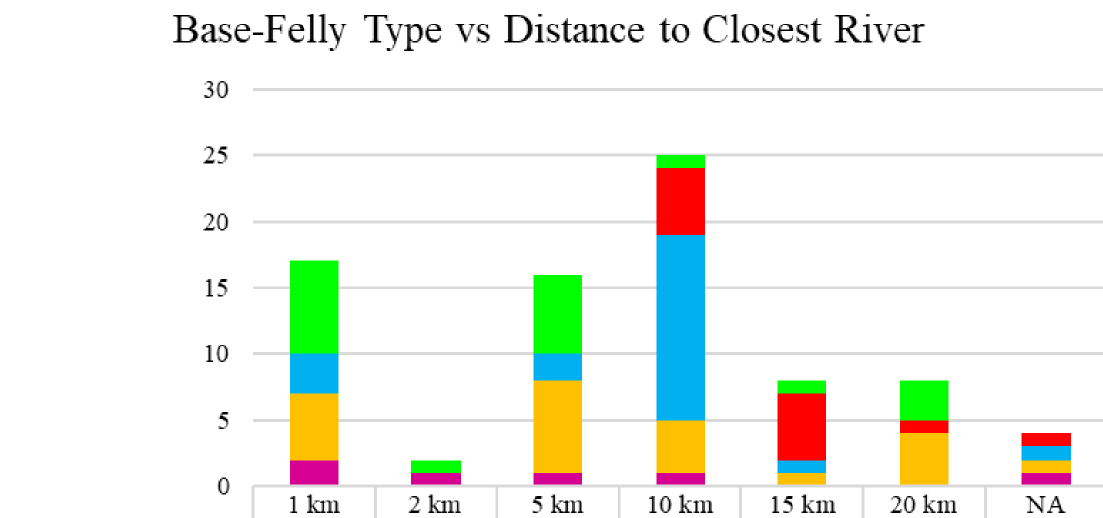
4.5.1 Spatial Variables and Base-and-Felly Types

The greatest number of Dharmacakras is located in Gleyic Acrisols (Ag) soil type which is suitable for growing rice (Figure 4.63). Dvāravatī people might take advantage from their site location to do agriculture and develop art materials. Mon style is shown mostly at the sites within 10 km closest to the river. Khmer style is occurred mostly at the sites within 5 km closest to the river. Funan style is appeared mostly at the sites within 1 km closest to the river. Mon-Khmer Mixed style can be found mostly at the sites within 10-15 km closest to river (Figure 4.64). Khmer style is found the mostly at the irregular/free-form plan sites, Mon and Mon-Khmer Mixed styles are occurred mostly at semi-rectangular plan sites, and Funan style is found only in polygonal and semi-rectangular plan sites (Figure 4.65). The greatest number of Khmer style is shown mostly in Si Thep which has an area of 4.692 SqKm. The other styles are existed mostly in Nakhon Pathom which has the largest area (Figure 4.66).



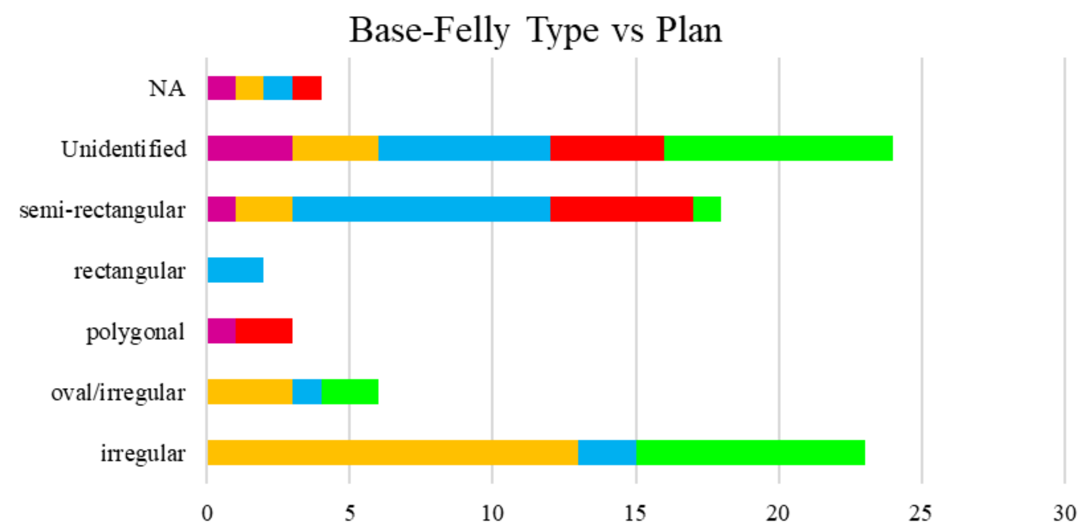
	Af	Ag	Ao	Gd	Ge	Je	Jt	Nd	Vp	NA
Unidentified	3	4	1	2		3		3	3	
Mon-Khmer Mixed		9			1				1	1
Mon	1	14	3						2	1
Khmer	3	6		2		5		4	1	1
Funan		2	1			1	1			1

Figure 4.63: A histogram shows number of Dharmacakras in each base and felly type by soil types



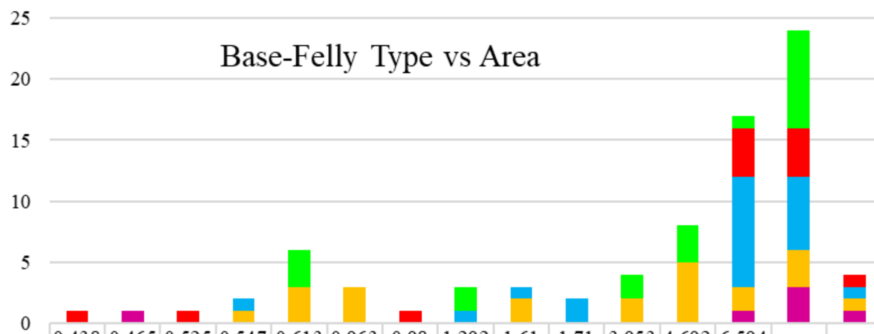
	1 km	2 km	5 km	10 km	15 km	20 km	NA
Unidentified	7	1	6	1	1	3	
Mon-Khmer Mixed				5	5	1	1
Mon	3		2	14	1		1
Khmer	5		7	4	1	4	1
Funan	2	1	1	1			1

Figure 4.64: A histogram shows number of Dharmacakras in each base and felly type by distance to the closest river



	irregular	oval/irregular	polygonal	rectangular	semi-rectangular	Unidentified	NA
Funan			1		1	3	1
Khmer	13	3			2	3	1
Mon	2	1		2	9	6	1
Mon-Khmer Mixed			2		5	4	1
Unidentified	8	2			1	8	

Figure 4.65: A histogram shows number of Dharmacakras in each base and felly type by site plan



	0.438 SqKm	0.465 SqKm	0.525 SqKm	0.547 SqKm	0.613 SqKm	0.963 SqKm	0.98 SqKm	1.292 SqKm	1.61 SqKm	1.71 SqKm	3.953 SqKm	4.692 SqKm	6.594 SqKm	Unidentied	NA
Unidentified					3			2			2	3	1	8	
Mon-Khmer Mixed	1		1				1						4	4	1
Mon				1				1	1	2			9	6	1
Khmer				1	3	3			2		2	5	2	3	1
Funan		1											1	3	1

Figure 4.66: A histogram shows number of Dharmacakras in each base and felly type by area

4.5.2 Inscriptions on Dharmacakras

So far, there are 5 sites, including Wat Saneha, Wat Pra Si Rattana Mahathat in Lop Buri, Si Thep, Sab Champa, and U Tapao in which 8 Dharmacakras that have inscriptions. These inscriptions include *Dhammacakkappavattana Sutta* and *Paṭiccasamuppāda* (Table 4.11 and Figure 4.67). Dharmacakras emphasize specific aspects of enlightenment as representing by their inscriptions. The inscriptions are mostly from the Pāli cannon, include: the Four Noble Truths, *Paṭiccasamuppāda* (the Law of Dependent Origination), and *Dhammacakkappavattana Sutta* (Setting the Wheel of Dhamma in Motion).

For instance, the inscription on CBB1 (B#5) has been studied by Coedès (1956) and Brown (1996). It is carved in Pāli and is divided into four sections: on the felly; on spokes; on the exterior band of the hub; and on the interior band of the hub (Brown 1996:99-100). The four parts of the inscription are from *Dhammacakkappavattana Sutta*, the first sermon of the Buddha in deer park at Sarnath and hence the Dharmacakra turning. The inscriptions present the Four Noble Truths which are suffering *(duḥkha)*, the cause of suffering *(samudaya)*, cessation of suffering *(nirodha)*, the path leading to the cessation of suffering *(magga).* Each of the truths is applied three times, in the knowledge of the truth *(saccañāṇaṁ),* the knowledge of what should be done *(kiccañāṇaṁ),* and the knowledge of what has been done *(katañāṇaṁ)* (Brown 1996:100). The Four Noble truths are inscribed on the felly on the twelve of the fifteen spokes. The inscriptions on CLP4, CLP8 (B#33), NMC2 (Brown: Fig 93), and CLP6 come from *Dhammacakkappavattana Sutta* which relate to the first sermon and the noble truth. The inscriptions on NMC31 (B#41) and NMC32 come from *Paṭiccasamuppāda*, the Law of Dependent Origination.

It should be noted that there are a number of inscriptions, which come from the Pāli cannon, found on other subjects that relate to Dharmacakras such as pillar and socle (see also Brown 1996:99-115). These inscriptions from Pāli cannon indicate an important knowledge of Dvāravatī artisans, monks, or scribes on Buddhism and the heart of Buddha's teaching which is the chain of causation and the Four Noble Truths. These carefully selected texts are considered appropriate to be displayed on the Dharmacakras since both texts and Dharmacakras represent the first teaching of the Buddha, *Dhammacakkappavattana Sutta*. Brown (1996) suggests that the Dvāravatī artisans attempted to fit the parts of the text with the parts of the wheel. For instance, the inscriptions on CBB1 and CLP8 are arranged in a counter-clockwise direction, in order that the viewers would see them in order as the wheel turned in a clockwise direction (Brown 1996:116).

Table 4.11: Inscriptions found on Dharmacakras

Inscription	**Site ID**	**Item ID**	**Site Name**
Dhammacakkappavattana Sutta	DCS1	CBB1	Wat Saneha
Dhammacakkappavattana Sutta	CS98	CLP4	Lop Buri (Wat Pra Si Rattana Mahathat)
Dhammacakkappavattana Sutta	CS98	CLP8	Lop Buri (Wat Pra Si Rattana Mahathat)
Dhammacakkappavattana Sutta	CS74	NMC2	Si Thep
Dhammacakkappavattana Sutta	CS91	CLP6	Sab Champa
Paṭiccasamuppāda	CS3	NMC25	U Tapao
Paṭiccasamuppāda	CS98	NMC32	Lop Buri (Wat Pra Si Rattana Mahathat)
Paṭiccasamuppāda	CS74	NMC31	Si Thep

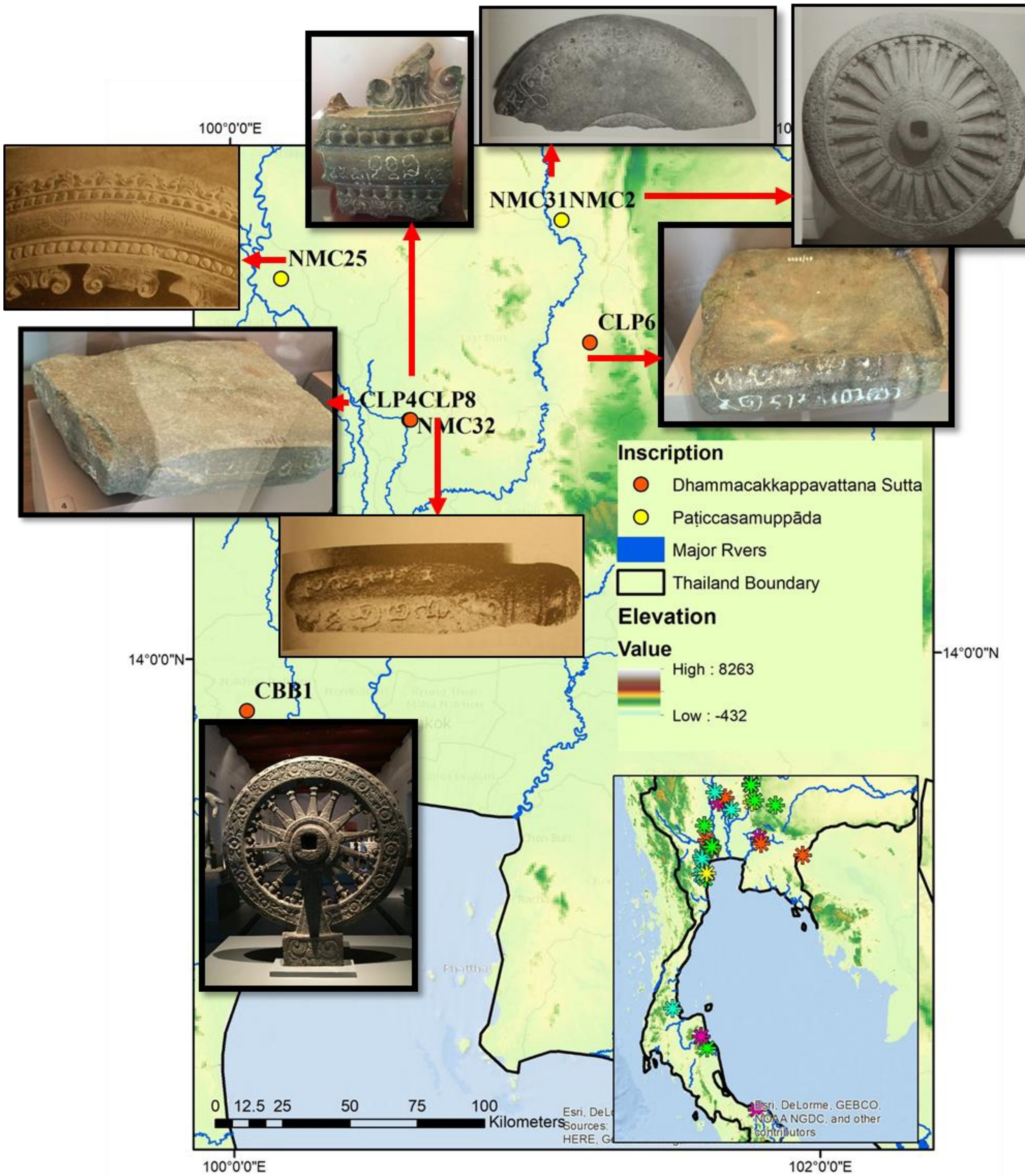


Figure 4.67: Inscriptions on Dharmacakras, map by Areerut Patnukao, basemap by Esri and other contributors (photos of NMC2 from Brown: Fig 6, NMC31 from Brown 1996: Fig 41, NMC25 from Indrawooth 2008a: Fig 36, NMC32 from Indrawooth 2008a: Fig 35)

4.6 Discussion

Analysis of settlement patterns offers an effective and practical mean of evaluating a wide variety of Dvāravatī cultural phenomena. The application of spatial and statistical analyses and methods to settlement research has enabled researches to examine some aspects of the interrelationships that existed between human populations and their natural and sociocultural environments. It is generally accepted that the geographical setting and the distribution of human settlements reflect these interrelationships to some degree and that analysis of settlement patterns should lead to meaningful statement about cultural processes and adaptation. The settlement patterns within a system reflect the kind of sociocultural structures and adaptive strategies used by a population. Assessment of elements, the structure, and the relationships that occur within a settlement pattern is one of the most efficient ways of approaching the question of cultural adaptation. Settlement pattern analysis is particularly open to the use of surface survey data. Many relevant and quantifiable attributes of individual settlement, as well as at overall systems, can be efficiently gathered through survey. This study relies largely on data from previous studies and present field survey in the analysis of the settlement system of Dvāravatī period.

Four different techniques are sequentially employed to analyze the Dvāravatī settlement system and Dharmacakra locations at three different geographic levels in Thailand, including national, regional, and river basin levels. NNA is used to test the spatial pattern of Dvāravatī settlements and Dharmacakra location. KDE is employed to examine the degree of site density and number of Dharmacakra density. Chi-Square is performed to test the relationships between sites and their environmental setting; and between the number of Dharmacakras and site-size. Finally, rank–size distributional analysis is applied to assess the general state of settlement system.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The main objective of this study is to integrate geographic technologies, spatial and statistical analyses, and archaeological field survey to study spatial patterns of Dharmacakra locations and Dvāravatī sites in Thailand. It was expected that this study could help identify the relationship between the number of Dharmacakra and the size of Dvāravatī sites, the relationship between Dharmacakra locations and their art styles. Furthermore, this study may broaden the understanding of the rise of Dvāravatī culture and the spread of Buddhism in early Thailand.

5.1 Conclusions

The approach used in this study demonstrates how the combination of GIS methods, statistical and spatial analyses, and a set of spatial variables can be used to quantify the location, size, density, and pattern of Dvāravatī settlements and Dharmacakra locations. The research has built on previous work data and present field survey data.

Four distinct approaches were used to evaluate the Dvāravatī settlements, Dharmacakra locations, and their relation throughout country in three different geographic levels, including national, regional, and river basin levels. Chi-Square analysis shows the significant relationships between sites and spatial variables which diverges among geographic levels. The KDE illustrates that the density of site placement varies among three geographic levels. The NNA reveals a unified clustered pattern of Dvāravatī settlements and Dharmacakra locations at the national level. However, in regional and river basin levels, the spatial patterns of Dvāravatī settlement are different.

Rank-Size distribution analysis reveals convex patterns of moated sites throughout the country which can be attributed to low system integration. Each settlement may be inhabited by an autonomous social group (Johnson 1980). It may indicate that settlements of two independent social systems have been integrated among settlements. Additionally, it may indicate the hindrance of communication by topography and poor transportation networks or discontinuous hierarchy (Johnson 1977).

5.1.1 Dvāravatī Settlements

The geographical locations have influences on Dvāravatī settlement since different locations relate to different spatial variables, for instance soil type, geology, elevation, and distance to the closest river. Dvāravatī sites are located to take advantage of geographical locations. In general, Dvāravatī sites are located below 50 m in elevation, with nearly level to undulating slope types, and within 2 km to closest river. The majority of sites are situated in Alluvial deposits and contain Gleyic Acrisols (Ag) which are suitable for growing rice. At the regional level, there are relationships between the sites in each region and their spatial variables, including geology type, soil type, distance to the closest river, and elevation. In the smaller geographic scale, river basin level, there are significant relationships between sites and spatial variables, including geology types and elevation.

Central Plain area and the river basins within this area have higher site density than other parts of the country. The greatest density is found along major rivers (e.g., Pang Prakong) or encircling the intersection of tributaries of the main rivers (e.g., Upper Chao Phraya). There are several potentials that may explain these variations in site densities. For example, the Central Plain area has the higher site density as a result of geographically locational advantages such as the fertile soil or easier access to the sea, which may cause both local and global interactions and trade network. Another possibility is an inconsistency of archaeology survey and excavation throughout the country, which may cause variations of data in some areas. Furthermore, presently lacking available data may also vary the results of site density.

The spatial pattern of Dvāravatī sites at the national level is clustered. While in smaller scales the results are different. At the regional level, Eastern region is only region that shows clustered pattern. A clustered pattern may be caused by several factors, such as localized resources and the emergence of polities or regional centers, as well as uneven survey or excavation. The random pattern is found in Central Plain and Western regions. The dispersed pattern is occurred in Northeastern and Southern regions. At the river basin level, there are more variety of the results. The clustered pattern is not present in this level. The random pattern is appeared only in Bang Prakong, Chao Phraya, Prachin Buri, and Tha Chin river basins. The dispersed pattern is the most occurred pattern in river basin level, including Chi, Mae Klong, Mun, Pa Sak, Pattani, Phetchaburi, Ping, Sakae Krang, and Thole Sap river basins. The dispersed pattern may indicate a degree of competition between settlements. This pattern usually has a service center or central place for exchanging food and products, as well as serving as administrative or religious centers (Hodder and Orton 1976).

The rank-size distribution of 59 Dvāravatī moated sites shows a convex pattern which indicates that several large settlements have similar size. This suggests that Dvāravatī settlement system may not be dominated by one single system but each settlement was inhabited by an autonomous social group. It also shows the lack of the discontinuous hierarchy. Another possibility is this pattern may be a result of geographic hindrances which may cause low connection and communication between adjacent settlement systems. The geological, pollen, spore, diatoms, and marine deposit evidences, suggests that sea level on the Chao Phraya delta reached its present level around 500 CE which was roughly the same time as the emergence of

Dvāravatī culture (Kanjanajuntorn 2006, Gallon 2013, Hutangkura 2014, and Songtham, et al. 2015). During this time, a mangrove belt covered most of ancient shoreline of the Lower Central Plain and limited human habitation since the deltic plain was too young, had low sediment, and experienced seasonal floods. These environment hindrances may emphasize a convex pattern of Dvāravatī settlements. The coastline during Dvāravatī period was relatively close to the present-day sea level. Thus, several Dvāravatī sites are situated on terrace along ca.8,000-7,000 years ago ancient coastline of Chao Phraya delta and further inland (Songtham, et al. 2015). These Dvāravatī sites could not be coastal settlements, but they might access to the Gulf of Thailand and maritime trade by rivers or canals that cut through massive mangrove swamps and wetlands (Gallon 2013).

5.1.2 Dharmacakra Locations

The result from NNA shows the clustered pattern of Dharmacakra locations across the country. The result from KDE shows the greatest density of Dharmacakras around Lower Central Plain while the greatest density is occurred around Mae Klong river basin (Nakhon Pathom) and expanded outward. The second highest density is existed around Pa Sak river basin where Si Thep and Sab Champa are located, these locations are second and third place respectively. The result from the rank-size distribution analysis of 13 moated sites in which 52 Dharmacakra were found shows a convex pattern which gives the same pattern of moated sites' rank-size analysis. There is a significant relationship between site size and the number of Dharmacakras. The larger site contains more number of Dharmacakras. This study shows that Nakhon Pathom is the largest moated site and contains the greatest number of Dharmacakra. However, it should be mentioned that since there was no systematic record or excavation, these items may have been transported from other places to be stored at the same place such as temples or the city centers. This could possibly explain why Nakhon Pathom contains the greatest number of Dharmacakras. In the further research, when additional data on Dharmacakra locations are applied, the analysis result may be altered.

So far, neither number of Dharmacakras nor their locations within the same site are adequate to indicate the regional centers or the boundary of Dvāravatī culture. However, the number of Dharmacakras relates to the size of sites which may emphasize an importance of those sites in which Dharmacakras were found. Moreover, since the origins of Dharmacakra locations are not so accurate, the result may be altered if there are additional data available or discovering more Dharmacakras in the future. In further research, the spatial distribution of other art materials or buildings should be incorporated to analyze the geographic boundary and centers of Dvāravatī culture.

Most of the sites can access the closest river within 2 km. Geographic location and neighboring cultures play important roles to base and felly styles of Dharmacakras. The patterns of base and felly on Dharmacakras reflect an influence of their neighboring cultures. For instance, Dharmacakras that found in the western and southern parts of the country are dominated by Mon style which geographically associates with Mon culture located in Myanmar. While Dharmacakras that discovered in the eastern part of the country are influenced by Funan and Mon-Khmer Mixed styles which again geographically relates to Khmer or Funan cultures situated in Cambodia and Vietnam around Mekong delta in the eastern part of Thailand.

The inscriptions that found on parts of Dharmacakras come from two major crucial texts in Pāli canon, *Paṭiccasamuppāda* (the Law of Dependent Origination) and *Dhammacakkappavattana Sutta* (Setting the Wheel of Dhamma in Motion). These carefully selected texts are considered appropriate to be presented on the Dharmacakras since both texts and Dharmacakras represent the first teaching of the Buddha. This emphasizes a significant knowledge of Dvāravatī artisans, monks, or scribes on Buddhism and the heart of Buddha's teaching which is the chain of causation and the Four Noble Truths.

5.2 Limitations

This study applies the use of GIS, spatial, and statistical methods to examine to spatial pattern of Dvāravatī settlement, Dharmacakra locations, and their relationships. However, the results obtained only apply to the available data sets hence further research requires more additional accurate data. The digitizing and calculating processes of the spatial variables are a time-consuming especially when the study data are limited. The classification of Dvāravatī settlement types is also the time-taking exercise since this classification has not been systematically done. There are some limitations of statistical analysis methods. For instance, the Chi-Square test is limited and suspected when worked with the small sample size. Commonly, when the expected frequency in a cell of a table is less than 5, Chi-Square can lead to inaccurate conclusion and should not be used. Therefore, some relationships between variables could not be tested due to small sample size.

During the pre-field survey, it took several days to contact and precede the request to access the data collection in each museum. The data in some museums were not systematically organized. There is no central database for all national museums. In order to get data or information, the researcher has to contact each museum in person. Several archaeological sites have been destroyed which could not be identified the boundary, but some are under protection. Additionally, some places that have been mentioned in previous works could not be detected on the Google Earth and some sites have minor errors in names' spelling.

Furthermore, the precisely original locations and number of Dharmacakras, size and number of moated sites, and other spatial variables were limited. The material sources, types of stones that are crafted Dharmacakras, and dating were also limited. The results obtained in this study may be altered when applied more accurate data sets or additional data. However, the results can be used as a basis for further studies on incorporating both spatial and archaeological data to examine settlement patterns in other cultures or different time periods.

This research focusses only on the analysis of spatial and environmental setting of Dvāravatī settlements. To fully understand the spatial patterns of settlements in Thailand and in Southeast Asia, further research on other cultures or other parts of Thailand and Southeast Asia should be carried out by incorporating appropriate spatial methods and archaeological data. This may help to better understand the comprehensive aspects of urbanization in Thailand and neighborhood areas.

5.3 Potential for Future Research

The settlement pattern analysis uncovers several problems that require further research. The most important question to be approached involves testing the result by assessing other aspects of the sites. This will require the collection of artifacts and other materials through excavation, site survey, and other appropriate approaches that can be used to test proposed settlement pattern and rank-site distribution analysis.

Spatial analysis approaches and GIS analysis used in this study require more evaluation of utility when applied to unsystematic record data. Several of analytical methods used here, for instance, Chi-Square, rank-size distribution analysis, Nearest Neighbor Analysis, and Kernel Density Estimate, although useful, require further testing and application with additional archaeological data. It is hoped that in near future these sorts of analysis will be used more frequently to test their usefulness in the assessment of settlement systems as well as the relationship between settlements and their environmental setting. In further research, several aspects of sites should be incorporated, for example number of moats, size, and activity.

The materials that are used to craft Dharmacakras should be tested by scientific methods or tools such as Portable X-ray fluorescence (PXRF) in order to trace back precise material sources to better understand the interaction between the Dvāravatī culture and their environment context or trade network.

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APPENDIX A

FIELD SURVEY

To collect the Dharmacakras' information and relevant documents, the surveys were carried out in four different areas which included Bangkok and three other routes in Thailand during December 2015 to February 2016. There are 78 items, including Dharmacakras and associated items retrieved from this field survey.

Bangkok

Several places in Bangkok were visited to obtain the data including Chulalongkorn University, Srinakharinwirot University, Silpakorn University, Bangkok National Museum, Fine Arts Department, and Department of Mineral Resources.

Figure A.1: Part of collections from Bangkok National Museum

Table A.1: Places visited and data collected from field work
Note: ^{B}=Base, $^{B+P}$= Base + Octagon Pillar, ^{D}=Deer, ^{C}= Complete Cakra, ^{FC}= Fragmented Cakra, ^{P}= Pillar, ^{S}= Stone site, *= Visited but no targeted item found, ^{F}= Dvāravatī Buddha footprint, $^{\#}$ = Reportedly Found items, $^{\&}$=No access items, ^{H}= Only deer head, $^{\wedge H}$= One with only head

#	**Region**	**Province**	**Name**	**B**	**D**	**C**	**FC**	**P**	**∑**
1	Central	Bangkok	Bangkok National Museum	1^{B+P}	4	5		1	**11**
		Nakhon Pathom	Wat Phra Pathom Chedi*						**0**
			Wat Phra Pathom Chedi Museum			2			**2**
			Wat Don Yai Hom$^{\&}$		1	1		1	**3**
			Phra Pathom Chedi National Museum	5	2	9	1	1	**18**
			Nern Pra site$^{\#}$						**0**
			Chula Pathon Chedi*						**0**
		Suphan Buri	U Thong National Museum	1	1^{H}	2	4	$2^{\wedge H}$	**10**
			Archaeological site No. 2 and 11$^{\#}$						**0**
		Sing Buri	In Buri National Museum			1			**1**
			Wat Bot museum (Part of In Buri Museum) *						**0**
		Lop Buri	Phra Narai National Museum	4	1		9	1	**15**
			Sap Champa Archaeological Site$^{\#}$						**0**
	Northeast	Nakhon Ratchasima	Phimai National Museum				2		**2**
			Sema Archealogical Site$^{\#}$						**0**
			Wat Dharmacakras Semaram			1		1	**2**
			Sandstone Quarry, Sikhiu*^{S}						**0**
	East	Prachin Buri	Prachin Buri National Museum			1			**1**
			Mueang Si Mahosot Archaeological Site$^{\#}$						**0**
			Mueang Si Mahosot District Office			1			**1**
			Wat Sramorakot*^{F}						**0**

(table cont'd.)

Table A.1 continued

#	Region	Province	Name	B	D	C	FC	P	∑
2	Central	Phetchabun	Si Thep			1			**1**
			Kao Klung Nok Archaeological Site*						**0**
		Sukhothai	Ramkhamhaeng National Museum			1			**1**
		Nakhon Sawan	Wat Tha Mai			1		1	**2**
			Wat Gai Chai Neur*						**0**
	West	Ratchaburi	Wat Klong Suwan Kiri*						**0**
			Khu Bua Archaeological Site*						**0**
		Phetburi	Wat Mahathat Worrawihan		1	1			**2**
			Wat Pa Paan*						**0**
			Wat Phet Pli						**2**
			Wat Nong Prong*						**0**
			Khao Yoi*[S]						**0**
3	South	Surat Thani	Chaiya National Museum			2	1		**3**
		Nakhon Sri Thammarat	Nakhon Sri Thammarat National Museum						**0**
			Wat Pramathad Woravihan			1			**1**
			Total	**11**	**10**	**32**	**17**	**8**	**78**

Route #1

This route includes the provinces in central, eastern, and northeastern parts of Thailand. It started from Trat, to Nakhon Pathom, Suphan Buri, Sing Buri, Lop Buri, Nakhon Ratchasima, Prachin Buri respectively, and back to Trat.

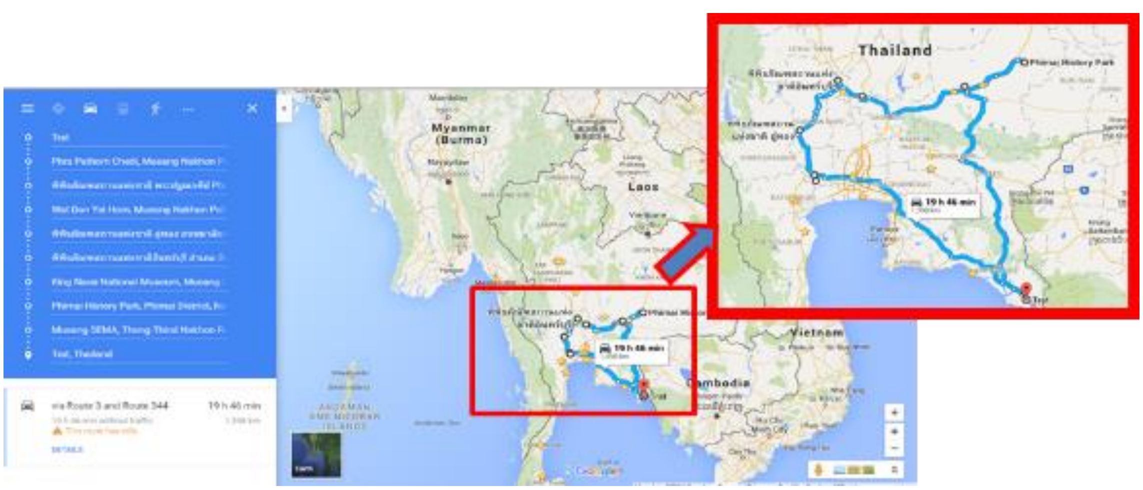

Figure A.2: Route #1 map

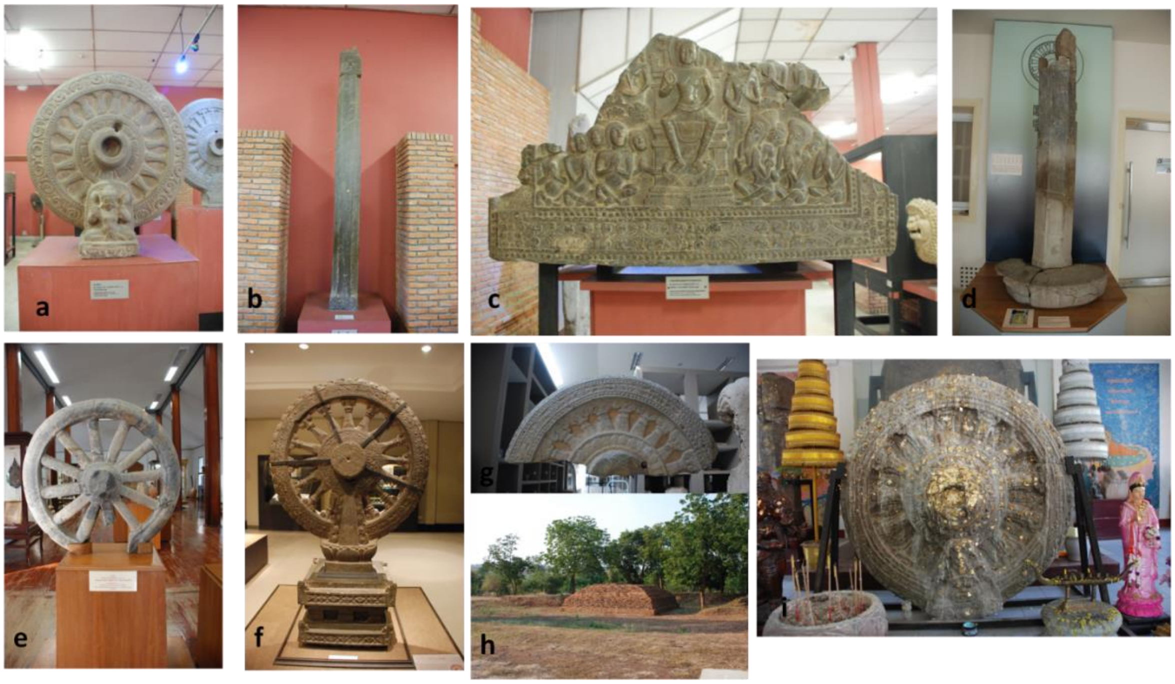

Figure A.2: Parts of Collections from Route #1: a-c) from Phra Pathom Chedi National Museum; d) (pillar) from Phra Narai National Museum; e) from In Buri National Museum; f-g) from U Thong National Museum; h) Archaeological Site No. 11 in U Thong; i) from Wat Dharmacakras Semaram

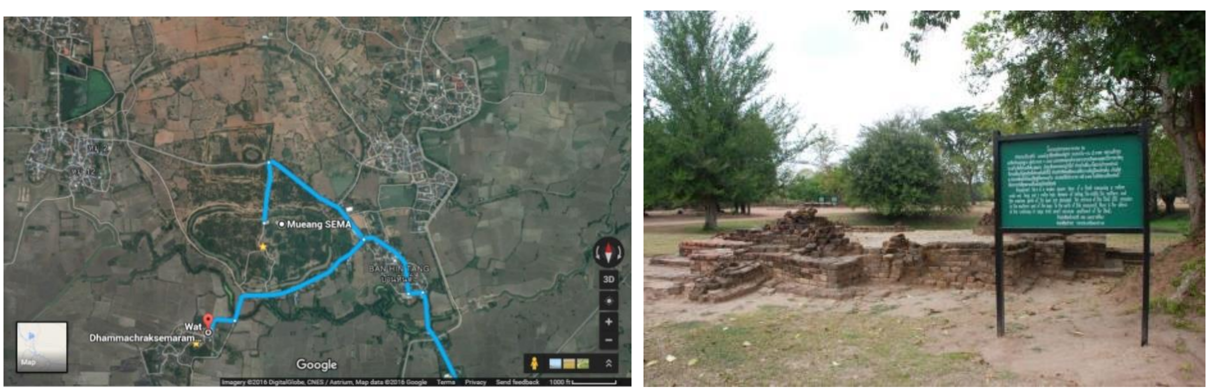

Figure A.3: Muang Sema Archaeological Site

Figure A.4: Sap Champa Archaeological Site, the current condition of site

Route #2

This route includes the provinces in central and western parts of Thailand. It started from Trat, to Phetchabun, Sukhothai, Nakhon Sawan, and Ratchaburi respectively and afterward went back to Trat.

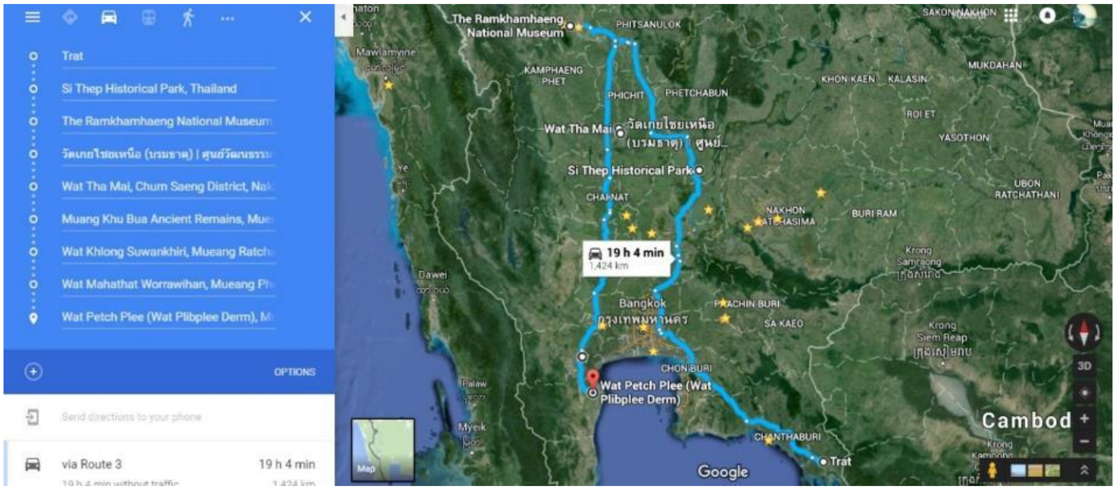

Figure A.5: Route#2 map

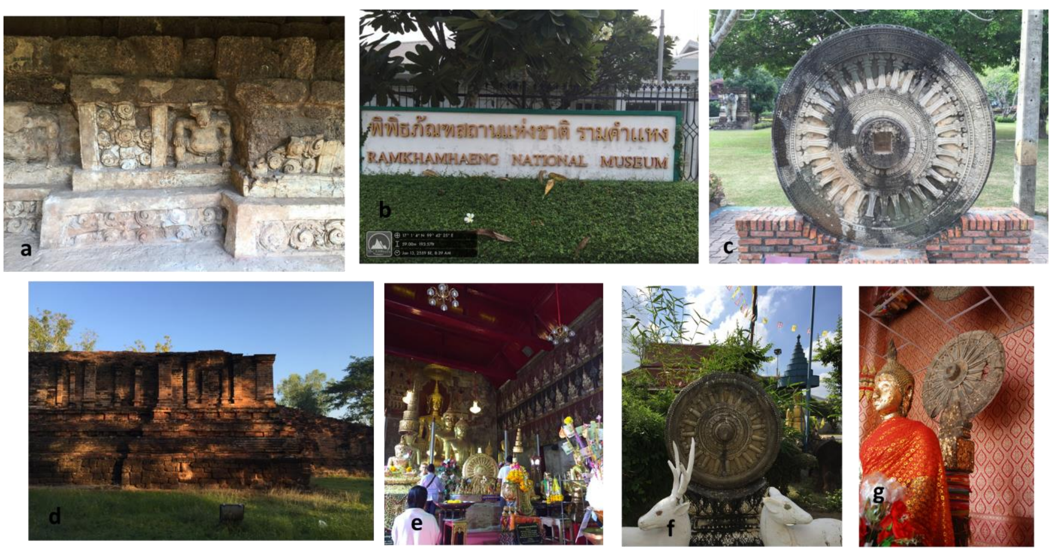

Figure A.6: Parts of Collections from Route#2: a) from Si Thep; b-c) from Ramkhamhaeng National Museum; d) is Ku Bua Archaeological Site; e) from Wat Mahathat Worrawihan, Phetchaburi; f) from Wat Phet Pli; g) from Wat Tha Mai

Route#3

This route includes the provinces in southern part of Thailand. It started from Trat, to Surat Thani and Nakhon respectively and afterward went back to Trat

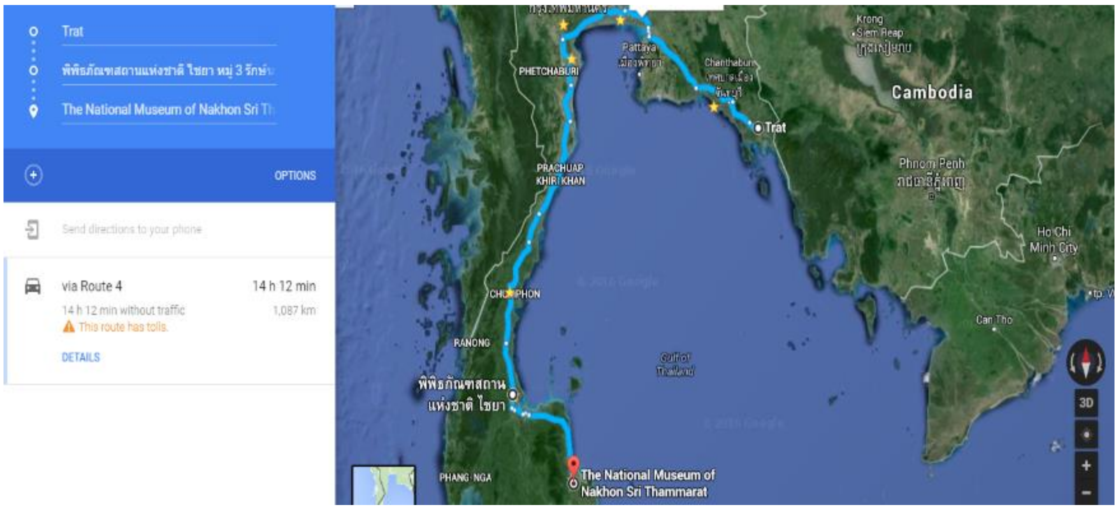

Figure A.7: Route#3 map

Figure A.8: Parts of Collections from Southern Route: a-b) from Chaiya National Museum; c) from Wat Pramathad Woravihan; d-e) from Nakhon Sri Thammarat National Museum

APPENDIX B

DATA OF DHARMACAKRAS AND ASSOCIATED ITEMS

Note: B=Base, B+P= Base + Octagon Pillar, D=Deer, DH=Deer Head, C= Complete Cakra, FC= Fragmented Cakra, P= Pillar, PH=Pillar Head

BNM = Bangkok National Museum , WPPCM = Wat Phra Pathom Chedi Museum, PPCNM=Phra Pathom Chedi National Museum, WDYH=Wat Don Yai Hom, UTNM=U Thong National Museum, IBNM=In Buri National Museum, PNNM=Phra Narai National Museum, PMNM=Phimai National Museum, WDS=Wat Dharmacakra Semaram, PCNM= Prachinburi National Museum, MSMDO= Muang Si Mahosot District Office, RNM=Ramkhamhaeng National Museum, WTM= Wat Tha Mai, WMW = Wat Mahathat Worrawihan, WPP=Wat Phet Pli, CNM=Chaiya National Museum, NSTNM=Nakhon Si Thammarat National Museum, WPMW=Wat Phra Mahathat Woramahawihan

For item ID, the first abbreviation refers as C= Cakra, B= Base, D= Dear, P= Pillar

NM= Not match with the Dvāravatī site record

NA= No data available

*Missing parts replaced with cement or plaster

Table B.1: Dharmacakras and associated items data from field survey

#	Item ID	Type	Site ID	Current Location	District	Province	Longitude	Latitude
1	DBB1	D	CS14	BNM	Muang	Nakhon Pathom	100.060574	13.819575
2	CBB1	C	NM	BNM	Muang	Nakhon Pathom	100.048406	13.825009
3	CBB2	C	CS74	BNM	Si Thep	Phetchabun	101.144	15.467
4	CBB3	C	WS22	BNM	Khao Yoi	Phetchaburi	99.918056	12.958333
5	DBB2	D	NA	BNM	NA	NA	NA	NA
6	CBB4*	C*	CS14	BNM	Mua ng	Nakhon Pathom	100.060574	13.819575
7	DBB3	D	CS14	BNM	Muang	Nakhon Pathom	100.060574	13.819575
8	CBB5	C	NA	BNM	NA	NA	NA	NA
9	BBB1	B+P	CS14	BNM	Muang	Nakhon Pathom	100.060574	13.819575
10	DBB4	D	NA	BNM	NA	NA	NA	NA
11	PBB1	P	ES28_1	BNM	Si Mahosot	Prachin Buri	101.42	13.9
12	CNW1	C	NM	WPPCM	Muang	Nakhon Pathom	100.067182	13.811298
13	CNW2	C	NM	WPPCM	Muang	Nakhon Pathom	100.067182	13.811298
14	CNP1	C	NA	PPCNM	NA	NA	NA	NA
15	BNP1	B	NA	PPCNM	NA	NA	NA	NA
16	BNP2	B	NA	PPCNM	NA	NA	NA	NA
17	CNP2	C	NA	PPCNM	NA	NA	NA	NA
18	PNP1	P	NA	PPCNM	NA	NA	NA	NA
19	CNP3	C	NA	PPCNM	NA	NA	NA	NA
20	CNP4	C	NA	PPCNM	NA	NA	NA	NA
21	CNP5	C	NA	PPCNM	NA	NA	NA	NA
22	CNP6	C	NA	PPCNM	NA	NA	NA	NA
23	CNP7	C	NA	PPCNM	NA	NA	NA	NA
24	CNP8	C	NA	PPCNM	NA	NA	NA	NA
25	BNP3	B	NA	PPCNM	NA	NA	NA	NA
26	BNP4	B	NA	PPCNM	NA	NA	NA	NA
27	BNP5	B	NM	PPCNM	Nakhon Chai Si	Nakhon Pathom	100.162605	13.784445
28	CNP9	C	CS40	PPCNM	Muang	Nakhon Pathom	100.055213	13.822929
29	CNP10	FC	NA	PPCNM	NA	NA	NA	NA
30	DNP1	D	NA	PPCNM	NA	NA	NA	NA

(table cont'd.)

Table B.1 continued

#	Item ID	Type	Site ID	Current Location	District	Province	Longitude	Latitude
31	DNP2	D	NA	PPCNM	NA	NA	NA	NA
32	CNN1	C	CS37	WDYH	Muang	Nakhon Pathom	100.086602	13.745087
33	DNN1	D	CS38	WDYH	Muang	Nakhon Pathom	NA	NA
34	PNN1	P	CS39	WDYH	Muang	Nakhon Pathom	NA	NA
35	CSU1	FC	NA	UTNM	NA	NA	NA	NA
36	PSU1	P	CS123	UTNM	U Thong	Suphan Buri	99.870362	14.37461
37	BSU1	B	CS123	UTNM	U Thong	Suphan Buri	99.870362	14.37461
38	CSU2	C	CS123	UTNM	U Thong	Suphan Buri	99.870362	14.37461
39	CSU3*	C	CS123	UTNM	U Thong	Suphan Buri	99.891899	14.37817
40	DSU1	DH	NA	UTNM	NA	NA	NA	NA
41	CSU4	FC	CS123	UTNM	U Thong	Suphan Buri	99.887857	14.370957
42	CSU5	FC	NA	UTNM	NA	NA	NA	NA
43	CSU6	FC	NA	UTNM	NA	NA	NA	NA
44	PSU2	PH	NA	UTNM	NA	NA	NA	NA
45	CSI1	C	CS105	IBNM	In Buri	Sing Buri	100.277729	14.994263
46	CLP1	FC	CS91	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
47	CLP2	FC	CS92	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
48	CLP3	FC	NM	PNNM	Ban Mi	Lop Buri	101.171188	15.010666
49	CLP4	FC	CS90	PNNM	Muang	Lop Buri	100.613905	14.79857
50	CLP5	FC	CS90	PNNM	Muang	Lop Buri	100.622305	14.802191
51	CLP6	FC	CS91	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
52	CLP7	FC	CS92	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
53	DLP1	D	NA	PNNM	NA	NA	NA	NA
54	CLP8	FC	NA	PNNM	NA	NA	NA	NA
55	CLP9	FC	CS91	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
56	BLP1	B	CS92	PNNM	Tha Luang	Lop Buri	101.240005	15.052407
57	PLP1	P	NA	PNNM	NA	NA	NA	NA
58	BLP2	B	NA	PNNM	NA	NA	NA	NA
59	BLP3	B	NA	PNNM	NA	NA	NA	NA
60	BLP4	B	NM	PNNM	NA	Prachin Buri	102.394693	13.747758
61	CNPN1	FC	NES31_1	PMNM	Sungnoen	Nakhon Ratchasima	101.7980556	14.92194444

(table cont'd.)

Table B.1 continued

#	Item ID	Type	Site ID	Current Location	District	Province	Longitude	Latitude
62	CNPN2	FC	NES31 _2	PMNM	NA	NA	101.7980556	14.92194444
63	CND1	C	NA	WDS	NA	NA	101.793456	14.916318
64	PND1	P	NA	WDS	NA	NA	101.793456	14.916318
65	CPP1	C	NM	PCNM	Aranyap rathet	Srakeao	102.52723	13.584047
66	CPM1	C	ES28	MSMDO	NA	NA	101.4075	13.88194444
67	CPS1*	C	CS74_1	Si Thep	Si Thep	Phetchabun	101.144522	15.487098
68	CSR1*	C	CS74_1	RNM	Si Thep	Phetchabun	101.144522	15.487098
69	CNT1	C	NA	WTM	NA	NA	100.246292	15.914842
70	PNT1	P	NA	WTM	NA	NA	100.246292	15.914842
71	CPWM1	C	NA	WMW	NA	NA	NA	NA
72	DPWM1	D	NA	WMW	NA	NA	NA	NA
73	CPWP1*	C	NA	WPP	NA	NA	NA	NA
74	CPWP2*	C	NA	WPP	NA	NA	NA	NA
75	CSC1	FC	NM	CNM	Chaiya	Surat Thani	99.044173	9.465307
76	CNSN1	FC	NM	NSTNM	Tha Sala	Nakhon Si Thammarat	99.806922	8.727006
77	CNSN2	FC	NM	NSTNM	Tha Sala	Nakhon Si Thammarat	99.806922	8.727006
78	CNSP1	C	NA	WPMW	Muang	Nakhon Si Thammarat	99.966145	8.410996

Table B.2: Dharmacakras from field survey and previous studies
Note: This appendix cooperated data from field and previous works. There are 49 Dharmacakra items from field survey and 31 items from only previous works. The art style classification was based on Brown's (1996) and Indorf (2014). For Item ID, data from the field survey are initiated with "C" (e.g. CNSN1) while those from only previous works are started with "N" (e.g. NMC13) FT= Felly Type following Brown's (1996) group numbers (1-6); BT= Base Type following Indorf's (2014) (1A-C, 2A-B, 3A-C); B+F = Base and Felly Type follow Indorf's (2014): F=Funan, K=Khmer, M=Mon, MK=Mon–Khmer mixed; B#(number) = Brown's Dharmacakra #(number) (1-42) (see detail in chapter 2 section 2.3.2)

Item ID	Site ID	FT	BT	B+F	References	Current Location
CNSN1	DCS5	6		F	B#42	NSTNM
CSI1	CS105	6		F	B#39	IBNM
NMC13	DCS15_PN	6		F	Brown 1966: Fig 93	PCNM
NMC14	NA	6	2A	F	Yupho 1990: Fig 13	BNM
NMC20	CS49	6	1B	F	B#40, Yupho: Fig 12	PPCNM

(table cont'd.)

Table B.2 continued

Item ID	Site ID	FT	BT	B+F	References	Current Location
NMC9	SS7	6	1C	F	B#38	not given
CBB1	DCS1	1	2A	K	B#5	BNM
CLP1	CS91	1		K	Indrawooth 2008a: p160 bottom	PNNM
CLP2	CS91	1		K	Indrawooth 2008a: p160 middle	PNNM
CLP3	DCS2	1		K	B#2	PNNM
CND1	NES31	1	2B	K	B#11	WDS
CNP1	CS49	1	1C	K	B#12	PPCNM
CNT1	CS3	1	2A	K	B#4	WTM
CNW1	DCS6	1	1C	K	B#14	PPCNM
CPS1	CS74_1	1	1B	K	Indrawooth 2008a: p164	Si Thep
CPWM1	WS23	1	2B	K	Yupho 1990: Fig 8	WMW
CPWP2	WS23	1		K	Indrawooth 2008a: p170 top right	WPP
CSU2	CS123	1	2A	K	B#3	UTNM
CSU3	CS123	1	2A	K	B#1	UTNM
CSU4	CS123	1		K	B#17	UTNM
NMC1	NA	1	2B	K	B#10	Guimet Museum, Paris, France
NMC10	CS74	1	1B	K	B#7	Private collection
NMC11	CS74	1	1B	K	B#8	Private collection
NMC12	CS74	1	1B	K	B#9	Private collection
NMC16	CS49	1	1C	K	Yupho 1990: Fig 15	Pra Pathom Chedi
NMC2	CS74	1	1B	K	B#6	Newark Museum, New Jersey, US
NMC24	CS91	1		K	Indrawooth 2008a: p160 top	Private collection
NMC26	NES31	1		K	Indrawooth 2008a: p167	not given
CLP8	CS98	5		M	B#33	PNNM
CNP2	CS49	5	1B	M	B#36	PPCNM
CNP3	CS49	4	3A	M	B#31	BNM
CNP6	CS49	2	3A	M	B#21	PPCNM
CNP7	CS49	5	3A	M	B#34	PPCNM
CNW2	DCS6	2	1B	M	B#23	PPCNM
CPWP1	WS23	5		M	Indrawooth 2008a: p170	WPP

(table cont'd.)

Table B.2 continued

Item ID	Site ID	FT	BT	B+F	References	Current Location
CSC1	DCS10	2	1A	M	Indrawooth 2008a: p174, center =B#19	CNM
NMC17	CS49	2	1A	M	Yupho 1990: Fig 19	not given
NMC18	NA	2		M	B#20	not given
NMC19	CS49	2	3A	M	Indrawooth 2008a: p131	PPCNM
NMC21	WS50	5		M	Indrawooth 2008a: p157, second to the top	not given
NMC22	DCS11	2		M	Indrawooth 2008a: p157 top	Wat Mahathat Ratchaburi (in situ)
NMC25	CS3	5		M	Indrawooth 2008a: Fig 36 (p122)	not given
NMC27	WS21	5		M	Indrawooth 2008a: p169 bottom	not given
NMC28	WS22	5	1B	M	Indrawooth 2008a: p169 top	not given
NMC29	WS20	2		M	Indrawooth 2008a: p172 top	not given
NMC5	CS49	4		M	B#27	Songkhla National Museum
NMC6	WS50	4		M	B#29	Wat Thong Chedi, Ratchaburi
NMC7	CS49	4		M	B#32	WPPCM
NMC8	CS49	5	3A	M	B#37	PPCNM
CBB4	CS14	1	1A	MK	B#13	BNM
CBB5	CS49	3	2B	MK	B#22	BNM
CNN1	CS37	1	1A	MK	Indrawooth 2008a: p147 =B#15	WDYH
CNP4	CS49	3	2B	MK	B#24	PPCNM
CNP5	CS48	5	3B	MK	B#35	UTNM
CNP8	CS49	4	2A	MK	B#30	PPCNM
CNP9	CS40	1	3B	MK	B#16	PPCNM
CPM1	ES28	1	3A	MK	B#18, Indrawooth 2008a: p165	MSMDO
CPP1	DCS9	2	2B	MK	B#26	PCNM
NMC15	CS49	3/2?	2B	MK	Yupho 1990: Fig 24	not given
NMC23	CS55	1		MK	Indrawooth 2008a: p158	not given
NMC4	NA	3	2A	MK	B#25	Suan Pakkad Palace, Bangkok
CBB2	CS74				Only Field Survey	BNM

(table cont'd.)

Table B.2 continued

Item ID	Site ID	FT	BT	B+F	References	Current Location
CBB3	WS22				Only Field Survey	BNM
CLP4	CS98				Only Field Survey	PNNM
CLP5	DCS4				Only Field Survey	PNNM
CLP6	CS91				Only Field Survey	PNNM
CLP7	CS91				Only Field Survey	private collection
CLP9	CS91				Only Field Survey	PNNM
CNP10	CS49				Only Field Survey	BNM
CNPN1	NES31_1				Only Field Survey	PMNM
CNPN2	NES31_1				Only Field Survey	PMNM
CNSN2	DCS5				Only Field Survey	NSTNM
CNSP1	DCS14_E				Only Field Survey	WPMW
CSR1	CS74_1				Only Field Survey	Si Thep
CSU1	DCS13_UN				Only Field Survey	UTNM
CSU5	DCS13_UN				Only Field Survey	UTNM
CSU6	DCS13_UN				Only Field Survey	UTNM
NMC30	CS14	19			B#28	WPPCM
NMC31	CS74				B#41	Private collection
NMC32	CS98				Indrawooth 2008a: Fig 35 (p121), p159 Top	PNNM

Table B.3: Dharmacakra's art information

Item ID	Site Name	Cut Spoke	Diameter (cm)	Height (cm)	#Of Spoke	Material
CBB1	Wat Saneha	yes	89	105	15	stone
CBB2	Si Thep	no	99	116	18	stone
CBB3	Ban Nongprong	no	93	115	18	stone
CBB4	Phra Pathom Chedi	no	200	219	35	stone
CBB5	Nakhon Pathom	no	70	91	12	stone
CLP1	Sab Champa	yes				stone
CLP2	Sab Champa	yes				stone
CLP3	Ban Thale Wang Wat	yes				stone
CLP4	Wat Pra Si Rattana Mahathat, Lop Buri	no*				stone
CLP5	Kai Naraisuksa School	no*				stone
CLP6	Sab Champa	no*				stone
CLP7	Sab Champa	no				terra-cotta

(table cont'd.)

Table B.3 continued

Item ID	Site Name	Cut Spoke	Diameter (cm)	Height (cm)	#Of Spoke	Material
CLP8	Lop Buri	yes				stone
CLP9	Sap Champa	no*				stone
CND1	Muang Sema	no	140		11	stone
CNN1	Nern Pra site	no				stone
CNP1	Nakhon Pathom	no	100	110	24	stone
CNP10	Nakhon Pathom	no	45		8	laterite
CNP2	Nakhon Pathom	no	80	90	16	stone
CNP3	Nakhon Pathom	no	100	113	22	stone
CNP4	Nakhon Pathom	no	65	70	16	stone
CNP5	Kamphaeng Saen	no	70	79	16	stone
CNP6	Nakhon Pathom	no	72	70	25	stone
CNP7	Nakhon Pathom	no	95	100	16	stone
CNP8	Nakhon Pathom	no	100	115	32	stone
CNP9	Wat Phra Ngam	no	76	86	16	stone
CNPN1	Monument No. 2, Sema	no		39		stone
CNPN2	Monument No. 2, Sema	no		31		stone
CNSN1	Wat Maheyong	yes		19		terra-cotta
CNSN2	Wat Maheyong	yes		19		terra-cotta
CNSP1	NA	yes	37			stone
CNT1	NA	no	100	115		stone
CNW1	Thung Phra Men	no	95	103	16	stone
CNW2	Thung Phra Men	no	84	99	20	stone
CPM1	Si Mahosot	no	81			stone
CPP1	Aranyaprathet District	no	77	77	14	stone
CPS1	Khao Klung Nok, Si Thep	no	181		29	stone
CPWM1	NA	no	103		24	stone
CPWP1	NA	no	90			stone
CPWP2	NA	no	109			stone
CSC1	Tambon Tung	yes		30		stone
CSI1	Ban Ku Muang	yes	83		13	slate
CSR1	Khao Klung Nok, Si Thep	no				stone
CSU1	NA	yes	37			stone
CSU2	Archaeological site No. 2, U Thong	yes	93	130	15	stone
CSU3	Archaeological site No.11, U Thong	no	86.5	130	11	stone

(table cont'd.)

Table B.3 continued

Item ID	Site Name	Cut Spoke	Diameter (cm)	Height (cm)	#Of Spoke	Material
CSU4	U Thong	no				stone
CSU5	NA	no	3.5	3		terra-cotta
CSU6	NA	no	2.8	3.3		terra-cotta
NMC1	unknow	no	160		12	stone
NMC10	Si Thep	no	178		29	stone
NMC11	Si Thep	no				stone
NMC12	Si Thep	yes				stone
NMC13	Si Maha Phot	no	17		12	stone
NMC14	unknow	no			12	stone
NMC15	Nakhon Pathom	no				stone
NMC16	Nakhon Pathom	no	104	114	24	stone
NMC17	Nakhon Pathom	no	65		18	stone
NMC18	unknow	no	99		20	stone
NMC19	NA	no	67		26	stone
NMC2	Si Thep	no	114.8		23	stone
NMC20	Nakhon Pathom	no	42		8	stone
NMC21	Ku Bua	yes				stone
NMC22	Wat Mahathat Ratchaburi	no				stone
NMC23	Chansen	no				stone
NMC24	Sap Champa	no				stone
NMC25	U Tapao	yes				stone
NMC26	Muang Sema	no				stone
NMC27	Ban Nong Chik	yes				stone
NMC28	Ban Nong Chik	no	94		18	stone
NMC29	Ban Lard	no				stone
NMC30	Phra Prathom Chedi	no				stone
NMC31	Si Thep	no			26	stone
NMC32	Wat Pra Si Rattana Mahathat	yes				stone
NMC4	unknow	no				stone
NMC5	Nakhon Pathom	no	65		20	stone
NMC6	Ku Bua	yes				stone
NMC7	Nakhon Pathom	no				stone
NMC8	Nakhon Pathom	no				stone
NMC9	Yarang	yes		35	8	stone

APPENDIX C

PHOTOS OF DHARMACAKRAS AND ASSOCIATED ITEMS

Figure C.1: DBB1

Figure C.2: CBB1 (left) front and (right) back

Figure C.3: CBB2 (left) front and (right) back

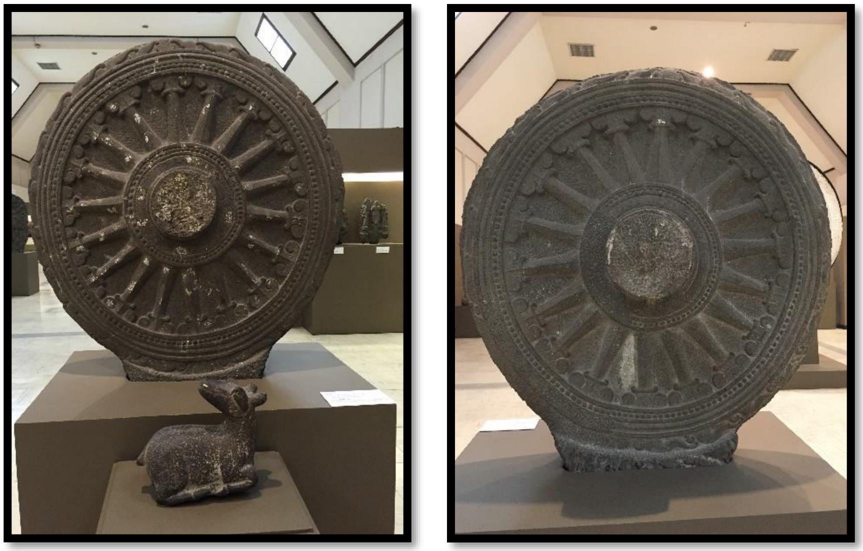

Figure C.4: CBB3 (left) front with DBB2 in front, and (right) back

Figure C.5: DBB2

Figure C.7: DBB3

Figure C.6: CBB4 (left) front with DBB3 in front and (right) back

Figure C.8: CBB5 (left) front and (right) back

Figure C.9: BBB1 (left) front and (right) back

Figure C.10: DBB4 (No image since could not access the item when visited the Bangkok National Museum)

Figure C.11: PBB1 (left) front and (right) back

Figure C.12: CNW1

Figure C.13: CNW2

Figure C.14: CNP1 (left) front and (right) back

Figure C.15: BNP1 **Figure C.16:** BNP2

Figure C.17: CNP2 (left) front and (right) back

Figure C.18: PNP1, top pillar (right)

Figure C.19: CNP3 (left) front and (right) back

Figure C.20: CNP4 (left) front and (right) back

Figure C.21: CNP5

Figure C.22: CNP6 (left) front and (right) back

Figure C.23: CNP7 (left) front and (right) back

Figure C.24: CNP8 (left) front and (right) back

Figure C.25: BNP3

Figure C.26: BNP4

Figure C.27: BNP5

Figure C.28: CNP9

Figure C.29: CNP10

Figure C.30: DNP1

Figure C.31: DNP2

Figure C.32: CNN1 (Brown 1996: Fig15)

Figure C.33: DNN1(courtesy of Wat Don Yai Hom)

Figure C.34: PNN1 (Khunsong 2010:47)

Figure C.35: CSU1

Figure C.36: PSU1

Figure C.37: BSU1

Figure C.38: CSU2 (left) front and (right) back

Figure C.39: CSU3

Figure C.40: DSU1

Figure C.41: CSU4 (left) front and (right) back

Figure C.42: CSU5

Figure C.43: CSU6

Figure C.44: PSU2

Figure C.45: CSI1 (left) front and (right) back

Figure C.46: CLP1

Figure C.47: CLP2

Figure C.48: CLP3

Figure C.49: CLP4

Figure C.50: CLP5

Figure C.51: CLP6

Figure C.52: CLP7

Figure C.53: DLP1

Figure C.54: CLP8

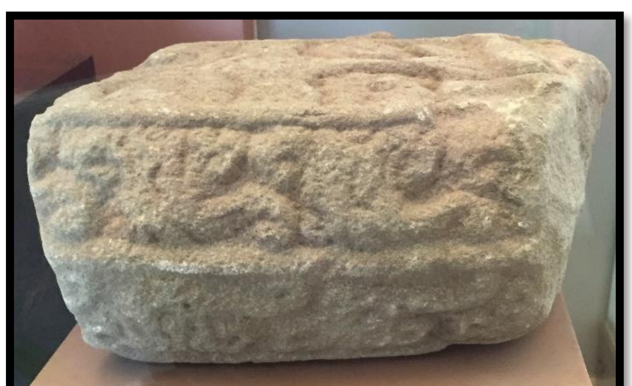

Figure C.55: CLP9

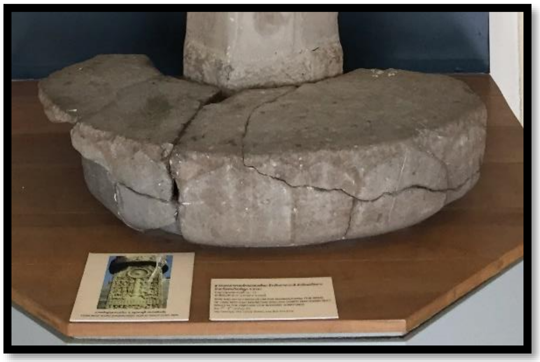

Figure C.56: BLP1

Figure C.57: PLP1

Figure C.58: BLP2

Figure C.59: BLP3

Figure C.60: BLP4

Figure C.61: CNPN1

Figure C.62: CNPN2

Figure C.63: CND1 **Figure C.64:** PND1

Figure C.65: CPP1 **Figure C.66:** CPM1

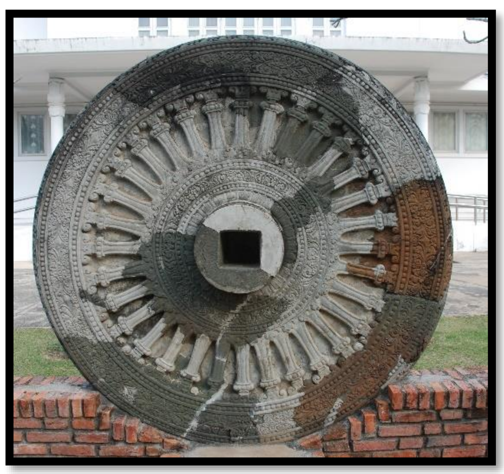

Figure C.67: CPS1 **Figure C.68:** CSR1

Figure C.69: CNT1

Figure C.70: PNT1

Figure C.71: CPWM1

Figure C.72: DPWM1 (no photo)

Figure C.73: CPWP1

Figure C.74: CPWP2

Figure C.75: CSC1

Figure C.76: CNSN1

Figure C.77: CNSN2

Figure C.78: CNSP1

APPENDIX D

SITE DATABASE

Table D.1: Dvāravatī Site Types and References
Note: The first letter of Site ID represents the region, expect Northeast uses NE. C = Central Plain, E = East, NE and L = Northeast (L maintains Murphy 2010: Table A1a, A1b sites), N = North, S = South, W = West. While the second letter "S" (the third letter of Northeast) means "Site".

Site_ID	Name_English	Name_Thai	Site_Type	References
CS1	Trai Trueng	เมืองไตรตรึงษ์	Ancient Town	FAD
CS10	Bang Kra Buang	เมืองโบราณบ้านบางกระเบื้อง	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:3.4
CS100	Panom Surin	เรือพนมสุรินทร์	Shipwreck Site	SAC
CS101	Kheetkhin	เมืองขีดขิน(คูเมือง)	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:12.3, Gallon 2013:B.21
CS102	Dong Muang	ดงเมือง	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:12.1, Gallon 2013:TableB.5-Unlocated
CS103	Bodhisattva Cave	ถ้ำพระโพธิสัตว์	Ancient Community	Pisnupong 1999, Indrawooth 1999
CS104	Wat Khao Wong (Narai Cave)	วัดเขาวง(ถ้ำนารายณ์)	Ancient Community	Pisnupong 1999, FAD
CS105	Ku Muang (Inburi)	คูเมือง (อินทร์บุรี)	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:14.1, Gallon 2013:B.10
CS106	Ban Keem	เมืองโบราณบ้านคีม	Ancient Town	Pisnupong 1999
CS107	Ban Ku	เมืองโบราณบ้านคู	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:14.3
CS108	Wat Chomchuen	วัดชมชื่น ต.2/	AS-Cemetery	SAC, FAD
CS109	Si Satchanalai Historical Park	เมืองศรีสัชนาลัย	Ancient Town	SAC

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS11	Muang Nang Lek	เมืองนางเหล็ก	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:8.3
CS111	Khao Phra	เขาพระ	RP-Chedi	FAD
CS112	Wat Khao Dee Salak	วัดเขาดีสลัก	RP-Chedi, Buddha Footprint	FAD
CS113	Wat Palelai Worawihan	วัดป่าเลไลย์วรวิหาร	RP-Ubosot, Vihara, Buddha Image	FAD
CS114	Ku Muang (Duembang Nangbuat)	เมืองโบราณบ้านคูเมือง (เดิมบางนางบาช)	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:13.9, Gallon 2013:B.9
CS115	Ban Don Yai Koi	ชุมชนโบราณบ้านดอนยายก่อย	Ancient Community	Pisnupong 1999
CS116	Ban Don Kha	แหล่งโบราณคดีบ้านดอนคา	AS-Cemetery	FAD
CS117	Ban Ning Bua	เมืองโบราณบ้านหนองบัว	Ancient Town	FAD
CS118	Ban Nong Hin	เมืองโบราณบ้านหนองหิน	Ancient Town	FAD
CS119	Ban Tha Pong	แหล่งโบราณคดีบ้านท่าโป่ง	AS-Artifacts Found	FAD
CS12	Dong Lakhon	ดงละคร	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:6.1
CS120	Kok Chang Din	คอกช้างดิน	RP-Ruin; PU-Pool	FAD
CS121	Wat Prasart	วัดปราสาท (ร้าง)	RP-Chedi	FAD
CS122	Nong Sam Rong	หนองสำโรง	Ancient Town	Indrawooth 1999, Gallon 2013:Table B.5-Unlocated
CS123	U Thong	อู่ทอง	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:13.2, Gallon 2013:B.6

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS124	Ban Nhong Jang	เมืองหนองแจง	Ancient Town	Pisnupong 1999
CS125	Ban Khok Samrong	ชุมชนโบราณบ้านโคกสำโรง	Ancient Community	Pisnupong 1999
CS126	Ban Don Makuer	ชุมชนโบราณบ้านดอนมะเกลือ	Ancient Community	Pisnupong 1999
CS127	Ban Tha Mung	ชุมชนโบราณบ้านท่าม่วง	Ancient Community	Pisnupong 1999
CS128	Ban Na Lao	ชุมชนโบราณบ้านนาลาว	Ancient Community	Pisnupong 1999
CS129	Ban Wang Yasai	เมืองโบราณบ้านวังหญ้าไทร (บ้านดอนทอง)	Ancient Town	Pisnupong 1999
CS13	Ban Kok Kradon	บ้านโคกกระโดน	Ancient Community	Pisnupong 1999
CS130	Ku Muang (Ang Thong)	คูเมือง (อ่างทอง)	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:15.2, Gallon 2013:B.8
CS132	Ban Dai	บ้านด้าย	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:16.4, Gallon 2013:Table B.5-Unlocated
CS133	Bung Khok Chang	บึงคอกช้าง	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.2, Gallon 2013:B.12
CS134	Muang Ka Rung	เมืองการุ้ง	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.1, Gallon 2013:B.15
CS135	Ban Thathong	ชุมชนโบราณบ้านท่าทอง	Ancient Community	Pisnupong 1999
CS136	Ban Pung Toei	ชุมชนบ้านผังเตย	Ancient Community	Pisnupong 1999

(table cont’d.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS137	Tung Prajan (Ban Ku/ Ban Nai Ku)	เมืองทุ่งประจาน (บ้านคู/ บ้านในคู)	Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.3
CS138	Ban Lumkao	ชุมชนบ้านหลุมเข้า	Ancient Community	Pisnupong 1999
CS14	Phra Prathom Chedi	พระปฐมเจดีย์	RP-Vihara, Chedi	FAD
CS15	Chedi Chula Pathon	เจดีย์จุลประโทน	RP-Chedi	FAD
CS16	Kok Jang	แหล่งโบราณคดีโคกแจง	AS-Artifacts Found	FAD
CS17	Ban Tha Kham	แหล่งโบราณคดีบ้านท่าข้าม	AS-Artifacts Found	FAD
CS18	Ban Nai Prasom Nagyai	แหล่งโบราณคดีบ้านนายประสม นาคใหญ่	AS-Artifacts Found	FAD
CS19	Ban Nai Swanthaya Sengsai	แหล่งโบราณคดีบ้านนายสรรค์ธยา เส็งสาย	AS-Artifacts Found	FAD
CS2	Sankhaburi	เมืองสรรค์บุรี	Ancient Town	Indrawooth 1999, Supajanya and Vanasin 1980:3.2, Gallon 2013:Table B.5-Unlocated
CS20	Ban Bo Tanod	แหล่งโบราณคดีบ้านบ่อโตนด	AS-Artifacts Found	FAD
CS21	Wat Klang	แหล่งโบราณคดีบ้านพระงาม(วัดกลาง)	AS-Artifacts Found	FAD
CS22	Ban Phum	แหล่งโบราณคดีบ้านภูมิ	AS-Artifacts Found	FAD
CS23	Ban Lan Thong	แหล่งโบราณคดีบ้านลานทอง	AS-Artifacts Found	FAD
CS24	Ban Suan Mai	แหล่งโบราณคดีบ้านสวนใหม่	AS-Artifacts Found	FAD
CS25	Ban Suan Cha-Om	แหล่งโบราณคดีบ้านสวนชะอม	AS-Artifacts Found	FAD
CS26	Ban Nong Jok	แหล่งโบราณคดีบ้านหนองจอก	AS-Artifacts Found	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS27	Ban Nong Arsia	แหล่งโบราณคดีบ้านหนองอาเสี่ย	AS-Artifacts Found	FAD
CS28	Ban Ajan Yupa	แหล่งโบราณคดีบ้านอาจารย์ยุพา เส็งสาย	AS-Artifacts Found	FAD
CS29	Wat Yai	แหล่งโบราณคดีวัดใหญ่	AS-Artifacts Found	FAD
CS3	U Tapao	เมืองอู่ตะเภา	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:3.3, Gallon 2013:B.17
CS30	Student Training Center	แหล่งโบราณคดีศูนย์ฝึกนักศึกษา	AS-Artifacts Found	FAD
CS31	Suan Pak	แหล่งโบราณคดีสวนผัก	AS-Artifacts Found	FAD
CS32	Grandville Village	แหล่งโบราณคดีหมู่บ้านแกรนด์วิว	AS-Artifacts Found	FAD
CS33	Sakaew Village	แหล่งโบราณคดีหมู่บ้านสระแก้ว	AS-Artifacts Found	FAD
CS34	Hor Eak	แหล่งโบราณคดีหอเอก	AS-Artifacts Found	FAD
CS35	Rai Nai Jew	ไร่นายจิ๋ว บุญรักษา	AS-Cemetery	FAD
CS36	Wat Koh Wang Sai	วัดเกาะวังไทร	AS-Artifacts Found	FAD
CS37	Wat Noen Pra	วัดเนินพระ (ร้าง)	RP-Chedi	FAD
CS38	Wat Dhammasara	วัดธรรมศาลา	RP-Chedi	FAD
CS39	Wat Phra Men	วัดพระเมรุ	RP-Chedi	FAD
CS4	Dong Khon	เมืองโบราณบ้านดงคอน	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:3.1, Gallon 2013:B.7
CS40	Wat Phra Ngam	วัดพระงาม	RP-Vihara	FAD
CS41	Wat Prathon Chedi Worawihan	วัดพระประโทน	RP-Chedi	FAD
CS42	Ban Don Kwaw	แหล่งโบราณคดีบ้านดอนเขว้า	AS-Artifacts Found	FAD
CS43	Kok Kratai	แหล่งโบราณคดีโคกกระต่าย	AS-Artifacts Found	FAD
CS44	Kok Pra	แหล่งโบราณคดีโคกพระ	AS-Artifacts Found	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS45	Tuk Kag	แหล่งโบราณคดีตึกแขก	AS-Artifacts Found	FAD
CS46	Bang Ra Tho	แหล่งโบราณคดีบางราโท	AS-Artifacts Found	FAD
CS47	Wat Kok Makam	วัดโคกมะขาม(ร้าง)	AS-Artifacts Found	FAD
CS48	Kamphaeng Saen	กำแพงแสน	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:7.2, Gallon 2013:B.4
CS49	Nakhon Pathom	นครปฐม	Ancient Town	Pisnupong 1999, Indrawooth 2008,Supajanya and Vanasin 1980:7.3, Gallon 2013:B.5
CS5	Khao Kayai	เขาขยาย	Ancient Community	Pisnupong 1999
CS50	Don Yai Hom	ดอนยายหอม	Ancient Community	Pisnupong 1999
CS53	Pra Kham	เมืองประคำ (บ้านโคกเดื่อ)	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.9, Gallon 2013:Table B.5-Unlocated
CS54	Aphaisali	อไภสาลี	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.10, Gallon 2013:Table B.5-Unlocated
CS55	Chansen	จันเสน	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.7, Gallon 2013:B.19
CS56	Don Kha	ดอนคา	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.13
CS57	Muang Bon	เมืองบน	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.2, Gallon 2013:B.14

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS58	Thap Chumphol	ทัพชุมพล	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.16
CS59	Muang Huai Duk	เมืองห้วยดุก	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.11
CS6	Nakon Noi	เมืองโบราณนครน้อย (บ้านหนองตาตน (2))	Ancient Town	Pisnupong 1999
CS60	Dong Mae Nang Muang,	ดงแม่นางเมือง	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.18
CS61	Ban Nongbuataklan	บ้านหนองบัวตากลาน	Ancient Community	Pisnupong 1999
CS62	Ban Nongnean (1)	บ้านหนองเนิน(๑)	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:8.6
CS63	Ban Huathanonklang	บ้านหัวถนนกลาง (เมืองสระแก้ว)	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:8.5
CS64	Wat Nang Kui	วัดนางกุย	RP-Buddha Image	FAD
CS65	Tan Klor	เมืองโบราณที่ตำบลทับคล้อ	Ancient Town	FAD
CS66	Ban Wan Dang	แหล่งโบราณคดีบ้านวังแดง	AS-Artifacts Found	FAD
CS67	Sa Peng	สระเพ็ง	PU-Pool	FAD
CS68	Klaep Cave	แหล่งโบราณคดีถ้ำแกลบ	AS-Artifacts Found	FAD
CS69	Ban Nean Krabuang	แหล่งโบราณคดีบ้านเนินกระเบื้อง	AS-Artifacts Found	FAD
CS7	Ban Klong Muay	เมืองโบราณบ้านคลองมวย	Ancient Town	Pisnupong 1999
CS70	Ban Chomphu	แหล่งโบราณคดีบ้านชมพู	AS-Artifacts Found	FAD
CS71	Wat Tham Pra	แหล่งโบราณคดีวัดถ้ำพระ	AS-Artifacts Found	FAD
CS72	Wat Tham Khun Ta Khan	วัดถ้ำขุนตะค้าน	AS-Artifacts Found	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS73	Wat Klang	วัดกลาง	RP-Ubosot, Vihara	FAD
CS74	Si Thep	ศรีเทพ	Ancient Town	Indrawooth 1999, Gallon 2013:B.28
CS74_1	Khao Klung Nok	เขาคลังนอก	Religious Place	FAD
CS74_2	Rusi Pagoda	ปรางค์ฤาษี (ปรางค์นอก)	RP-Pagoda	FAD
CS74_3	Khao Klung Nai	เขาคลังใน	Archaeological Site	SAC
CS74_4	Prang Sri Thep	ปรางค์ศรีเทพ	Archaeological Site	SAC
CS77	Khao Thamorat Cave	ถ้ำเขาถมอรัตน์	AS-Cave/Shelter	Indrawooth 1999
CS8	Ban Nong Bua	บ้านหนองบัว	Ancient Town	Pisnupong 1999
CS80	Muang Lop Buri Fortress	ป้อมปราการเมืองลพบุรี	PU-Moat,City Wall; OP-Arch, Fortress	FAD
CS81	Wat Nakorn Kosa	วัดนครโกษา(ร้าง)	RP-Vihara, Pagoda	FAD
CS82	Wat Puen	วัดปืน(ร้าง)	RP-Vihara, Chedi; PU-Water-well	FAD
CS83	Ban Thakae	บ้านท่าแค	Ancient Community	Pisnupong 1999
CS84	Ban Prang Noi	บ้านปรางค์น้อย	AS-Cemetery	FAD
CS85	Ban Mai Phaisali	บ้านใหม่ไพศาลี	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:11.6, Gallon 2013:TableB.5-Unlocated
CS86	Promtin Tai	พรหมทินใต้	Ancient Town	Pisnupong 1999, Indrawooth 1999, SAC, Mudar 1999, SAC, Supajanya and Vanasin 1980:11.2, Gallon 2013:B.23
CS87	Wang Phai	วังไผ่	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:Table B.5-Unlocated

(table cont’d.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
CS88	Chai Badan	ชัยบาดาล	Ancient Town	Indrawooth 1999, Gallon 2013:Table B.5-Unlocated
CS89	Dong Marum	ดงมะรุม	Ancient Town	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.20
CS9	Ban Thung Krathin	บ้านทุ่งกระถิน	Ancient Community	Pisnupong 1999
CS91	Sab Champa	เมืองโบราณซับจำปา	Ancient Town	Pisnupong 1999, FAD, SAC, Gallon 2013:B.27
CS93	Khao Pra Ngarm	เขาพระงาม	Ancient Community	Pisnupong 1999
CS94	Muang Sing Kuyang	เมืองสิงห์คูยาง (โคกคูเมือง)	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:11.4
CS95	Khao Rae	ชุมชนเขาแร่	Ancient Community	Pisnupong 1999
CS96	Nean Makok	ชุมชนเนินมะกอก	Ancient Community	Pisnupong 1999
CS97	Ban Kern Krathin	ชุมชนบ้านเกริ่นกระถิน	Ancient Community	Pisnupong 1999
CS98	Muang Lavo	เมืองละโว้ (ลพบุรี)	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:11.1, Gallon 2013:B.22
CS99	Ban Khom Shipwreck	แหล่งเรือจมบ้านขอม	PU-Habor; AS-Artifacts Found; Other-Shipwreck Site	FAD
ES1	Kho Kwang_Boat	เรือเกาะขวาง (เกาะฝาง)	Shipwreck Site	FAD
ES10	Nean Khun Yai	เนินคุณยาย	Ancient Community	Pisnupong 1999
ES11	Nean Ban Nai Tum	เนินบ้านนายตุ้ม	Ancient Community	Pisnupong 1999
ES12	Nean Samrong	เนินสำโรง	Ancient Community	Pisnupong 1999
ES13	Ban Don Lang	บ้านดอนล่าง	Ancient Community	Pisnupong 1999
ES14	Praya Re	เมืองพญาเร่	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:4.3

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
ES15	Nean Suan Nai	เนินสวนนาย	Ancient Community	Pisnupong 1999
ES2	Ban Ku Muang	เมืองบ้านคูเมือง	Ancient Town	Pisnupong 1999, Supajanya and Vanasin 1980:2.1
ES28	Si Mahosot	เมืองศรีมโหสถ	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:9.2, Gallon 2013:B.25
ES28_1	Archaeological Site # 009 (Ban Khok Wat)	โบราณสถานหมายเลข 009 (บ้านโคกวัด)	RP-Ritual Site	FAD
ES28_10	Sa Kaew	สระแก้ว	PU-Pool	FAD
ES28_13	Archaeological Site # 007,024 Si Mahosot	โบราณสถานหมายเลข 007,024	PU-Pool	FAD
ES28_11	Sa Morakot	สระมรกต (สระมรกฎ)	PU-Pool	FAD
ES28_14	Archaeological Site # 115 Si Mahosot	โบราณสถานหมายเลข 115	PU-Water-well	FAD
ES28_12	Sa Ma Khur	สระมะเขือ	PU-Water-well	FAD
ES28_15	Archaeological Site # 113 Si Mahosot	โบราณสถานหมายเลข 113	PU-Water-well	FAD
ES28_16	Archaeological Site # 043, 044 Si Mahosot	โบราณสถานหมายเลข 043,044	PU-Water-well	FAD
ES28_17	Archaeological Site # 045 Si Mahosot	โบราณสถานหมายเลข 045 (บ้านสระมะเขือ)	Residence	FAD
ES28_18	Archaeological Site # 4(077) Si Mahosot	เนินโบราณสถานหมายเลข 4(077)	RP-Building Base	FAD
ES28_19	Archaeological Site # 23(131) Si Mahosot	โบราณสถานหมายเลข 23(131)	RP-Chedi, Vihara; PU-Pool	FAD
ES28_2	Archaeological Site # 13 Sa Kraton	โบราณสถานหมายเลข 13 สระกระท้อน	PU-Pool	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
ES28_3	Archaeological Site # 16(027) Si Mahosot	โบราณสถานหมายเลข 16(027)	RP-Vihara	FAD
ES28_4	Archaeological Site # 17(028) Si Mahosot	โบราณสถานหมายเลข 17(028)	RP-Chedi; PU-Water-well	FAD
ES28_5	Archaeological Site # 19 (030), 20 (031), 038, 039 Si Mahosot	โบราณสถานหมายเลข 19 (030), 20 (031), 038, 039	RP-Building Base; Residence	FAD
ES28_6	Archaeological Site # 223 Si Mahosot	โบราณสถานหมายเลข 223	Religious Place	FAD
ES28_7	Archaeological Site # 11 (003) Si Mahosot	โบราณสถานหมายเลข 11(003)	AS-Artifacts Found; RP-Vihara	FAD
ES28_8	Phu Khao Thong	ภูเขาทอง	RP-Chedi; PU-Water-well	FAD
ES28_9	Wat Sa Morakot	วัดสระมรกต	Archaeologica l Site	FAD
ES28_20	Archaeological Site # 121 Si Mahosot	โบราณสถานหมายเลข 121 (สระขนุน)	PU-Pool	FAD
ES29	Khao Duan	เขาด้วน	Ancient Community	Pisnupong 1999
ES3	Ban Plaeng Yao	ชุมชนบ้านแปลงยาว	Ancient Community	Pisnupong 1999, FAD
ES30	Ban Doi Lampu	บ้านดอยลำภู	Ancient Community	Pisnupong 1999
ES31	Ban Hoi	เมืองโบราณที่บ้านหอย	Ancient Town	Pisnupong 1999
ES32	Ban Sa Morakot	ชุมชนสระมรกต	Ancient Community	Pisnupong 1999
ES33	Kok Khang	บ้านโคกขวาง	Ancient Community	Pisnupong 1999, Supajanya and Vanasin 1980:9.1
ES34	Sa Tarod	ชุมชนสระตารอด	Ancient Community	Pisnupong 1999
ES35	Sa Noi	ชุมชนสระน้อย	Ancient Community	Pisnupong 1999
ES36	Sa Yai Lung	ชุมชนสระยายลั้ง	Ancient Community	Pisnupong 1999
ES37	Muang Phai	เมืองไผ่	Ancient Town	Pisnupong 1999, FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
ES38	Prasat Khao Noi	ปราสาทเขาน้อย	RP-Prasart	FAD
ES39	Prasat Muang Phai	ปราสาทเมืองไผ่	RP-Pagoda	FAD
ES4	Ban Kok Hua Kao	ชุมชนโบราณบ้านโคกหัวข้าว	Ancient Community	Pisnupong 1999, FAD
ES40	Khao Chakan	เขาฉกรรจ์	Ancient Community	Pisnupong 1999
ES41	Tha Kaserm (1)	เมืองโบราณที่ตำบลท่าเกษม (1)	Ancient Town	Pisnupong 1999
ES42	Ban Han Sai	เมืองโบราณที่บ้านหันทราย	Ancient Town	Pisnupong 1999
ES43	Tha Kaserm (2)	เมืองโบราณที่ตำบลท่าเกษม (2)	Ancient Town	Pisnupong 1999
ES5	Ban Sa Song Torn	ชุมชนบ้านสระสองตอน	Ancient Community	Pisnupong 1999, FAD
ES6	Bung Kra Jub	ชุมชนบึงกระจับ	Ancient Community	Pisnupong 1999, FAD
ES7	Muang Phra Rot	เมืองพระรถ	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:4.2, Gallon 2013:B.26
ES8	Nean Koh Klang	เนินเกาะกลาง	Ancient Community	Pisnupong 1999
ES9	Nean Khun Dis	เนินคุณดิศ	Ancient Community	Pisnupong 1999
NS1	Haripunjaya	หริภุญไชย	Ancient Town	Indrawooth 1999
L1	Ban Sema/Muang Fa Daed	บ้านเสมา	RP-Sema	Murphy 2010:Table A1a, A1b
L10	Ban Song Bueai	บ้านสงเปือย	RP-Sema	Murphy 2010:Table A1a, A1b
L100	Ban Non Sala	บ้านโนนศาลา	RP-Sema	Murphy 2010:Table A1a, A1b
L101	Ban Thung Wang	บ้านทุ่งวัง	RP-Sema	Murphy 2010:Table A1a, A1b
L102	Ban That	บ้านธาตุ	RP-Sema	Murphy 2010:Table A1a, A1b
L103	Ban Choeng Doi	บ้านเชิงดอย	RP-Sema	Murphy 2010:Table A1a, A1b
L104	Ban Phu Phek	บ้านภูเพ็ก	RP-Sema	Murphy 2010:Table A1a, A1b

(table cont’d.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
L105	Ban Khok Khon	บ้านโคกคอน	RP-Sema	Murphy 2010:Table A1a, A1b, SAC, FAD
L106	Ban Peng Chan	เมืองเปงจารเก่า(เปงจาน)	RP-Sema	Murphy 2010:Table A1a, A1b, FAD
L107	Ban Cham Pi	บ้านจำปี	RP-Sema	Murphy 2010:Table A1a, A1b
L108	Ban Khon Sai	บ้านคอนสาย	RP-Sema	Murphy 2010:Table A1a, A1b
L109	Ban Thung Yai	บ้านทุ่งใหญ่	RP-Sema	Murphy 2010:Table A1a, A1b
L11	Ban Hua Muang	บ้านหัวเมือง	RP-Sema	Murphy 2010:Table A1a, A1b
L110	Ban Oup Mong	บ้านอูบมุง	RP-Sema	Murphy 2010:Table A1a, A1b, FAD
L111	Ban Truem	บ้านตรึม	RP-Sema	Murphy 2010:Table A1a, A1b
L12	Ban Bueng Kaeo	บ้านบึงแก	RP-Sema	Murphy 2010:Table A1a, A1b
L13	Ban Ku Chahn	บ้านกู่จาน	RP-Sema	Murphy 2010:Table A1a, A1b
L14	Ban Nahm Kum Yai	บ้านน้ำคำใหญ่	RP-Sema	Murphy 2010:Table A1a, A1b
L15	Ban Kum Ngoen	บ้านขุมเงิน	RP-Sema	Murphy 2010:Table A1a, A1b
L16	Ban Nohn Muang	บ้านโนนเมือง	RP-Sema	Murphy 2010:Table A1a, A1b
L17	Ban Phai Hin	บ้านฝายหิน	RP-Sema	Murphy 2010:Table A1a, A1b
L18	Ban Pho Chai	บ้านโพธิ์ไชย	RP-Sema	Murphy 2010:Table A1a, A1b
L19	Non Sema Fa Ranguem	โนนเสมาฟ้าระงึม	RP-Sema	Murphy 2010:Table A1a, A1b
L2	Ban Sohksai	บ้านโสกทราย	RP-Sema	Murphy 2010:Table A1a, A1b
L20	Ban Nohn Chat	บ้านโนนชาติ	RP-Sema	Murphy 2010:Table A1a, A1b
L21	Ban Bua Semaram	บ้านบัวสิมาราม	RP-Sema	Murphy 2010:Table A1a, A1b
L22	Ban Non Song	บ้านโนนฆ้อง	RP-Sema	Murphy 2010:Table A1a, A1b
L23	Ban Hua Kua/Ban Bua	บ้านหัวขัว/บ้านบัว	RP-Sema	Murphy 2010:Table A1a, A1b
L24	Ban Nong Hin Tang	บ้านหนองหินตั้ง	RP-Sema	Murphy 2010:Table A1a, A1b
L25	Ban Pao	บ้านเป้า	RP-Sema	Murphy 2010:Table A1a, A1b
L26	Ban Kut Ngong	บ้านกุดโง้ง	RP-Sema	Murphy 2010:Table A1a, A1b
L27	Ban Nong Kai Nun	บ้านหนองไข่นุ่น	RP-Sema	Murphy 2010:Table A1a, A1b
L28	Ban Nong Hin Tang	บ้านหนองหินตั้ง	RP-Sema	Murphy 2010:Table A1a, A1b
L29	Muang Gao	บ้านเมืองเก่า	RP-Sema	Murphy 2010:Table A1a, A1b
L3	Ban Nong Hang	บ้านหนองห้าง	RP-Sema	Murphy 2010:Table A1a, A1b
L30	Ban Phan Lam	บ้านพรรณลำ	RP-Sema	Murphy 2010:Table A1a, A1b

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
L31	Ban Kaeng	บ้านแก้ง	RP-Sema	Murphy 2010:Table A1a, A1b
L32	Ban Korn Sawan	บ้านคอนสวรรค์	RP-Sema	Murphy 2010:Table A1a, A1b
L33	Ban Maung Prai	บ้านเมืองไพร	RP-Sema	Murphy 2010:Table A1a, A1b
L34	Ban Phanom Phrai	บ้านพนมไพร	RP-Sema	Murphy 2010:Table A1a, A1b
L35			RP-Sema	Murphy 2010:Table A1a, A1b
L36	Ban PoTong	บ้านโพธิ์ทอง	RP-Sema	Murphy 2010:Table A1a, A1b
L37	Ban Sra	บ้านสระ	RP-Sema	Murphy 2010:Table A1a, A1b
L38			RP-Sema	Murphy 2010:Table A1a, A1b
L39	Ban Puey Huadong	บ้านเปือยหัวดง	RP-Sema	Murphy 2010:Table A1a, A1b, SAC, FAD
L4	Ban Na Ngam/Ban Dorn Sila	บ้านนางาม	RP-Sema	Murphy 2010:Table A1a, A1b
L40	Ban Chat	บ้านชาด	RP-Sema	Murphy 2010:Table A1a, A1b
L41	Ban Nah Mo Ma	บ้านนาหมอม้า	RP-Sema	Murphy 2010:Table A1a, A1b
L42	Ban Muang Samsip		RP-Sema	Murphy 2010:Table A1a, A1b
L43	Ban Phon Muang	บ้านโพนเมือง	RP-Sema	Murphy 2010:Table A1a, A1b
L44	Ban Salaeng Thon	บ้านแสลงโทน	RP-Sema	Murphy 2010:Table A1a, A1b
L45	Ban Brakum		RP-Sema	Murphy 2010:Table A1a, A1b
L46	Ban Muang Fai	บ้านฝ้าย	RP-Sema	Murphy 2010:Table A1a, A1b
L47	Ban Pa Khiap and Ban Nohn Soong	บ้านปะเคียบ/บ้านโนนสูง	RP-Sema	Murphy 2010:Table A1a, A1b
L48	Phu Phra Angkhan	ภูพระอังคาร	RP-Sema	Murphy 2010:Table A1a, A1b
L49	Ban Hin Tang	บ้านหินตั้ง	RP-Sema	Murphy 2010:Table A1a, A1b
L5	Ban Sangkhom Phathana	บ้านสังคมพัฒนา	RP-Sema	Murphy 2010:Table A1a, A1b
L50	Ban Tanot	บ้านโตนด	RP-Sema	Murphy 2010:Table A1a, A1b
L51	Ban Lupmohk	บ้านหลุบโมก	RP-Sema	Murphy 2010:Table A1a, A1b
L52	Ban Nong Kluem	บ้านหนองคลึม	RP-Sema	Murphy 2010:Table A1a, A1b
L53	Ban Hin Tang	บ้านหินตั้ง	RP-Sema	Murphy 2010:Table A1a, A1b, FAD
L54	Ban Ma	บ้านม้า	RP-Sema	Murphy 2010:Table A1a, A1b
L55	Ban Ruean Rahsat, Ban Pahkbeng, Ban Noinah, Ban Nohn Kok gleean	บ้านเรือนราษฎร/บ้านปากเป่ง/วัดบ้านน้อยนา/บ้านโนนกกเกลี้ยง	RP-Sema	Murphy 2010:Table A1a, A1b
L56	That Panom	ธาตุพนม	RP-Sema	Murphy 2010:Table A1a, A1b

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
L57	Phra Baht Historical Park	บ้านเมืองพาน	RP-Sema	Murphy 2010:Table A1a, A1b
L58	Ban Chiang	บ้านเชียง	RP-Sema	Murphy 2010:Table A1a, A1b
L59	Nong Hahn	หนองหาน	RP-Sema	Murphy 2010:Table A1a, A1b
L6	Ban Kunchinarai	บ้านกุฉินารายณ์	RP-Sema	Murphy 2010:Table A1a, A1b
L60	Ban Pailom	บ้านไผ่ล้อม	RP-Sema	Murphy 2010:Table A1a, A1b
L61	Ban Podahk	บ้านโพธิ์ตาก	RP-Sema	Murphy 2010:Table A1a, A1b
L62	Ban Pu Noi	บ้านภูน้อย	RP-Sema	Murphy 2010:Table A1a, A1b
L63	Ban Tah Wat	บ้านท่าวัดใต้	RP-Sema	Murphy 2010:Table A1a, A1b
L64	Ban Tah Krasoem	บ้านท่ากระเสริม	RP-Sema	Murphy 2010:Table A1a, A1b
L65	Ban Sri Than	บ้านศรีฐาน	RP-Sema	Murphy 2010:Table A1a, A1b
L66	Ban Muang Dao	บ้านเมืองเตา	RP-Sema	Murphy 2010:Table A1a, A1b
L67	Ban Khon Sai	บ้านคอนสาย	RP-Sema	Murphy 2010:Table A1a, A1b
L68	Ban Na Oi	บ้านนาอ้อย	RP-Sema	Murphy 2010:Table A1a, A1b
L69	Ban Nong Pai	บ้านหนองไผ่	RP-Sema	Murphy 2010:Table A1a, A1b
L7	Ban Don Kaeo	บ้านดอนแก้ว	RP-Sema	Murphy 2010:Table A1a, A1b
L70	Ban Daeng	บ้านแดง	RP-Sema	Murphy 2010:Table A1a, A1b
L71	Ban Na-ang	บ้านนาอ่าง	RP-Sema	Murphy 2010:Table A1a, A1b
L72			RP-Sema	Murphy 2010:Table A1a, A1b
L73	Ban Kor		RP-Sema	Murphy 2010:Table A1a, A1b
L74	Ban Kud Namkin	กุดน้ำกิน	RP-Sema	Murphy 2010:Table A1a, A1b
L8			RP-Sema	Murphy 2010:Table A1a, A1b
L9	Ban Tat Tong	บ้านตาดทอง	RP-Sema	Murphy 2010:Table A1a, A1b
L93	Ban Panna	บ้านพันนา	RP-Sema	Murphy 2010:Table A1a, A1b
L94	Ban Si Bua	บ้านศรีบัว	RP-Sema	Murphy 2010:Table A1a, A1b
L95	Ban Lak Sila	บ้านหลักศิลา	RP-Sema	Murphy 2010:Table A1a, A1b
L96	Ban Fang Daeng	บ้านฝั่งแดง	RP-Sema	Murphy 2010:Table A1a, A1b
L97	Ban Saphang Thong	บ้านสะพังทอง	RP-Sema	Murphy 2010:Table A1a, A1b
L98	Ban Na Ngam	บ้านนางาม	RP-Sema	Murphy 2010:Table A1a, A1b
L99	Wiang Khuk	วัดสาวสุวรรณนาราม	RP-Sema	Murphy 2010:Table A1a, A1b
NES1	Muang Fa Daed Song Yang	เมืองโบราณฟ้าแดดสงยาง	Ancient Town	Indrawooth 1999, Gallon 2013:B.34
NES10	Phra That Ya Khu	พระธาตุยาคู(ธาตุนายใหญ่)	RP-Chedi	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
NES11	Phukow Cave	ถ้ำภูค่าว	AS-Cave/Shelter	FAD
NES12	Wat Sawang Pho Si Tha Ngam	วัดสว่างโพธิ์ศรีท่างาม	AS-Artifacts Found	FAD
NES13	Wat Chaeng Sawang Nai	พระอุโบสถ(สิม)วัดแจ้งสว่างใน	RP-Sema, Ubosot	FAD
NES14	Ban Non Bo	ใบเสมาหินทรายและพระพุทธรูปบ้านโนนบ่อ	RP-Sema	FAD
NES15	Ban Pong Dang	บ้านโป่งแดง	AS-Artifacts Found	FAD
NES16	Ban Nanang	บ้านยานางและโบราณสถานโนนแท่นพระ	AS-Artifacts Found	FAD
NES17	Lao Kok Gyew	แหล่งโบราณคดีเหล่ากกงิ้ว	AS-Artifacts Found	FAD
NES18	Phu Khok MA	แหล่งตัดหิน ภูคอกม้าและภูกระแต	AS-Ancient Industry Site-Stone Cutting	FAD
NES19	Non Muang Ancient Town	ใบเสมาที่พบใหม่บริเวณใกล้เคียงเมืองโบราณโนนเมือง	RP-Sema	FAD
NES2	Phu Po	พระพุทธไสยาสน์ภูปอ	AS-Cave/Shelter	FAD
NES20	That Don Ku	ธาตุ(ดอนกู่)	RP-Sema, Chedi	FAD
NES21	Phu Phra	ภูพระ	AS-Cave/Shelter	FAD
NES22	Ban Muang Kao	บ้านเมืองเก่า	Archaeological Site	SAC
NES23	Ban Non Kong	บ้านโนนฆ้อง	RP-Sema	FAD
NES24	Chaiyaphum	ชัยภูมิ	Ancient Town	Indrawooth 1999, Gallon 2013:B.32
NES25	Ban Tu	บ้านทู้	RP-Sema	FAD
NES26	Muang Nakhon Panom	เมืองนครพนม	Ancient Town	SAC
NES27	Prathat Phanom	พระธาตุพนม	RP-Chedi	SAC
NES28	Muang Phimai	เมืองพิมาย	Ancient Town	FAD
NES29	Ban Prasart	บ้านปราสาท	Ancient Town	Supajanya and Vanasin 1984(I):20-44/234, FAD
NES3	Wat Nuea	วัดเหนือ (ใบเสมาหน้าวิหารวัดเหนือ)	RP-Sema	FAD
NES30	Sikew Stone Cutting Site	แหล่งหินตัดสีคิ้ว	AS-Ancient Industry Site-Stone Cutting	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
NES31	Muang Sema	เมืองเสมา	Ancient Town	Indrawooth 1999, Gallon 2013:B.29
NES31_1	Archaeological Site # 2 Muang Sema	โบราณสถานหมายเลข 2 เมืองเสมา	Archaeological Site	SAC
NES31_2	Archaeological Site # 3 Muang Sema	โบราณสถานหมายเลข 3 เมืองเสมา	Archaeological Site	SAC
NES31_3	Archaeological Site # 4 Muang Sema	โบราณสถานหมายเลข 4 เมืองเสมา	Archaeological Site	SAC
NES31_4	Archaeological Site # 5 Muang Sema	โบราณสถานหมายเลข 5 เมืองเสมา	Archaeological Site	SAC
NES31_5	Archaeological Site # 7 Muang Sema	โบราณสถานหมายเลข 7 เมืองเสมา	Archaeological Site	SAC
NES31_6	Archaeological Site # 8 Muang Sema	โบราณสถานหมายเลข 8 เมืองเสมา	Archaeological Site	SAC
NES31_7	Archaeological Site # 9 Muang Sema	โบราณสถานหมายเลข 9 เมืองเสมา	Archaeological Site	SAC
NES39	Wat Dhammacakra Semaram	วัดธรรมจักรเสมาราม	Religious Place	SAC
NES4	Ban Makom	ใบเสมาบ้านมะก้อม	RP-Sema	FAD
NES40	Muang Fhai	เมืองฝ้าย	Ancient Town	Indrawooth 1999
NES41	Putthai Song	เมืองพุทไธสง	Ancient Town	Indrawooth 1999, Gallon 2013:B.31
NES42	Ban Kho Yai	บ้านค้อใหญ่	AS-Artifacts Found	FAD
NES43	Don Hin Long	ดอนหินหล่อง	AS-Artifacts Found	FAD
NES44	Ban Hin Tung	บ้านหินตั้ง	AS-Artifacts Found	FAD
NES45	Dunlumpan	ป่าดูนลำพัน	AS-Artifacts Found	FAD
NES46	Nan Dong Noi	แหล่งโบราณคดีบ้านดงน้อย	AS-Artifacts Found	FAD
NES47	Na Dune	บ้านนาดูน	Ancient Town	Indrawooth 1999, Gallon 2013:B.30
NES48	Kantharawichai	กันทรวิชัย	Ancient Town	Supajanya and Vanasin 1984(II):41-1/8, Gallon 2013:B.33
NES49	Prathat Na Dune	พระธาตุนาดูน	Archaeological Site	SAC
NES5	Ban Sung Yang	ใบเสมาบ้านสูงยาง	RP-Sema	FAD
NES50	Muang Nakon Jampasri	เมืองนครจำปาศรี	Ancient Town	Thammarungruang 2015

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
NES51	Dong Muang Toei	ชุมชนโบราณดงเมืองเตย	Ancient Town	Thammarungruang 2015, FAD, SAC
NES52	Ban Si Than	ดงศิลาแลงใกล้บ้านศรีฐาน	RP-Sema	FAD
NES53	Ban Tat Thong	เมืองโบราณบ้านตาดทอง	Ancient Town	Thammarungruang 2015
NES55	Prasert Hin Ban Nong Kun (Don Khun Gyen)	ปราสาทหินบ้านหนองคูณ(ดอนขุมเงิน)	RP-Prasart; PU-Pool	FAD, SAC
NES56	Wat Nuea	วัดเหนือ	RP-Sema	FAD
NES57	Wat Bueng Phra Lan Chai	วัดบึงพระลานชัย	RP-Sema	FAD
NES58	Wat Sa Phang Thong	วัดสระพังทอง(วัดสระทอง)	RP-Sema	FAD
NES59	Ban Kum Sila	เสมาบ้านเหมืองแบ่งหรือคุ้มศิลา	RP-Sema	FAD
NES6	Ban Nong Pan	ใบเสมาบ้านหนองแปน	RP-Sema	FAD
NES60	Wat Ta Kaek	วัดท่าแขก	Religious Place	SAC
NES661	Muang Khong Khok	เมืองคงโคก	Ancient Town	FAD
NES662	Wat Ban Ma (Wat Si Rattanaram)	วัดบ้านม้า (วัดศรีรัตนาราม)	RP-Sema	FAD
NES663	Pra Cave	ถ้ำพระ	AS-Cave/Shelter	FAD
NES664	Wat Klang Si Changmai	วัดกลางศรีเชียงใหม่	RP-Sema	FAD
NES665	Don Suan Mak	ดอนสวนหมาก	RP-Sema	FAD
NES666	Wat Don Kam	วัดดอนกรรม	RP-Sema	FAD
NES667	Don HIn Lak	แหล่งโบราณคดีดอนหินหลัก	RP-Sema	FAD
NES668	Phu Papueng	แหล่งตัดหินภูผาผึ้ง	AS-Ancient Industry Site-Stone Cutting	FAD
NES669	Wat Pa Udom Phatthana	วัดป่าอุดมพัฒนา	RP-Sema	FAD
NES670	Wat Choeng Doi Theppharat	วัดเชิงดอยเทพรัตน์	RP-Buddha Image Engravings	FAD
NES672	Wat Katsapamathurom	วัดกัสสปะมะธุโรม (วัดป่าหนองกก)	AS-Artifacts Found, RP-Building Base	FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
NES674	Wat Phu Kaba	ใบเสมาวัดภูนกกะบา	RP-Sema	FAD
NES675	Phu Noi (Wat Santitham Banpot)	ภูน้อย (วัดสันติธรรมบรรพต)	RP-Sema	FAD
NES676	Wat Pa Si Wilai	วัดป่าศรีวิไล	RP-Sema	FAD
NES677	Sema Site Ban Nai Kunakorn	แหล่งใบเสมาหลังบ้านนายคุณากร พันธุ์โภคา	RP-Sema	FAD
NES678	Sema Site Don Tapu	แหล่งใบเสมาหินทรายดอนตาปู่ (หลักบ้าน)	RP-Sema	FAD
NES679	Ban Non Samran	บ้านโนนสำราญ	RP-Sema	FAD
NES680	Ban Pon Muang	บ้านโพนเมืองหรือโนนขวาว	RP-Sema	FAD
NES681	Wat Pho Sila	วัดโพธิ์ศิลา	RP-Sema	FAD
NES683	Muang Gyew	เมืองงิ้ว	Ancient Town	SAC
NES685	Chedi in Aom Rudi Park	เจดีย์ (ร้าง) ในอุทยานอ้อมฤดี	RP-Chedi	FAD
NES686	Phu Pha Daeng	รอยพระพุทธบาทภูผาแดง	RP-Buddha Footprint	FAD
NES687	Nong Duang	รอยพระพุทธบาทหนองด้วง	RP-Buddha Footprint	FAD
NES688	Wat Sungkaw	โบราณสถานวัดสังคาว	RP-Sema	FAD
NES689	Ban Nong Ung	บ้านหนองอึ่ง	RP-Sema	FAD
NES690	Wat Look Kei	เพิงหินด้านตะวันออกวัดลูกเขย	AS-Cave/Shelter-Rock Painting	SAC, FAD
NES691	Wat Pa Samukkee Non Kud	โบราณสถานวัดป่าสามัคคีโนนกุด	RP-Ubosot	FAD
NES692	Kho Phupan	แหล่งใบเสมาบริเวณเชิงเขาภูพาน	RP-Sema	FAD
NES695	Phu Phra Bat (Ku Nang Usa)	ภูพระบาท (กู่นางอุสา)	AS-Cave/Shelter	FAD
NES7	Ban Nong Hang	บ้านหนองห้าง	RP-Sema	FAD
NES8	Lak Tod	หลักทอด	RP-Sema	FAD
NES9	Hin Pan	หินแป้น	RP-Sema	FAD
SS4	Ban Cha Le	เมืองโบราณบ้านจาเละ	Ancient Town	SAC
SS5	Ban Prawa	เมืองโบราณบ้านประแว	Ancient Town	SAC
SS6	Ban Wat	เมืองโบราณบ้านวัด	Ancient Town	SAC
SS7	Yarang	เมืองโบราณยะรัง	Ancient Town	SAC
WS8	Archaeological Site # 3 Ban Cha Le	โบราณสถานบ้านจาเละหมายเลข 3	Religious Place	SAC

(table cont'd.)

Table D.1 continued

Site_ID	**Name_English**	**Name_Thai**	**Site_Type**	**References**
WS1	Pong Tuk	พงตึก	Ancient Community	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:1.1, Gallon 2013:B.3(Unmoated)
WS10	Khao Phra	เขาพระ	AS-Artifacts Found	FAD
WS12	Nong Prong	หนองปรง	AS-Artifacts Found	FAD
WS13	Nean Din Dang	เนินดินแดง	AS-Artifacts Found	FAD
WS14	Ban Rai Huay	บ้านไร่ห้วย	AS-Artifacts Found	FAD
WS15	Ban Nong Pra	บ้านหนองพระ	AS-Artifacts Found	FAD
WS19	Ban Tha Rua	บ้านท่าเรือ	AS-Artifacts Found, Ancient Industry Site	Indrawooth 2008, FAD
WS2	Ban Tha Wi	บ้านท่าหวี	Ancient Community	Pisnupong 1999
WS20	Ban Lard	บ้านลาด	AS-Ancient Industry Site	Indrawooth 2008
WS21	Ban Nong Chik	บ้านหนองจิก	AS-Ancient Industry Site	Indrawooth 2008, Silapanth 2006
WS22	Ban Nongprong	ชุมชนโบราณบ้านหนองปรง	Ancient Community	Pisnupong 1999
WS23	Phetchaburi	เพชรบุรี	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:5.1
WS24	Nean Pho Yai	โบราณสถานเนินโพธิ์ใหญ่	Ancient Community	Pisnupong 1999
WS25	Wat Papan	วัดป่าแป้น	Ancient Community	Pisnupong 1999, FAD
WS26	Khao Tachin	เขาตาจีน	Archaeological Site	SAC
WS27	Thung Setti	ทุ่งเศรษฐี	Ancient Community	Pisnupong 1999, SAC, FAD, Gallon 2013:B.1(Unmoated)
WS28	Khao Jom Prasart	โบราณสถานบนเขาจอมปราสาท	Archaeological Site	SAC
WS29	Ban Khao Krachiu	บ้านเขากระจิว	Ancient Community	Pisnupong 1999, SAC, FAD

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
WS3	Ban Wang Pato	ชุมชนโบราณบ้านวังปะโท่	Ancient Community	Pisnupong 1999
WS30	Ban Mai	บ้านใหม่	Ancient Community	Pisnupong 1999, SAC, FAD
WS31	Ban Mab Pla Khao	บ้านมาบปลาเค้า	Ancient Community	Pisnupong 1999, SAC, FAD
WS32	Ban Kok Sethi	บ้านโคกเศรษฐี	AS-Ancient Industry Site-Earthenware Production	SAC, FAD
WS33	Ban Don Tao It	บ้านดอนเตาอิฐ	Ancient Community	Pisnupong 1999, SAC, FAD
WS34	Chedi Hak	เจดีย์หัก	RP-Chedi	FAD
WS35	Wat Mahathat	วัดมหาธาตุวรวิหาร	RP-Ubosot, Vihara, Pagoda, Wall	FAD
WS36	Wat Luang	วัดหลวง	RP-Ubosot, Chedi, Sema, Wall	FAD
WS37	Khao Ngu Cave	ถ้ำเขางู	Ancient Community	Pisnupong 1999, Indrawooth 1999
WS38	Wat Mahathat Woravihara	วัดมหาธาตุวรวิหาร	Ancient Community	Pisnupong 1999
WS39	Wat Pa Kai	วัดป่าไก่	RP-Chedi Base	FAD
WS40	Wat Rim Kumuang	วัดริมคูเมือง (ร้าง)	AS-Artifacts Found	FAD
WS41	Wat Koh Nammatha Pathawalancharam	วัดเกาะนัมทาปทวลัญชาราม	AS-Artifacts Found	FAD
WS43	Ban Pratu Muang	บ้านประตูเมือง	AS-Artifacts Found	FAD
WS44	Ban Rang Phur	บ้านรางเฟื้อ	AS-Artifacts Found	FAD
WS45	Wat Rap Nam	วัดรับน้ำ (ขุนสีห์)	AS-Artifacts Found	FAD
WS46	Ban Kok Pra	บ้านโคกพระ	AS-Artifacts Found	FAD
WS50	Ku Bua	คูบัว	Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:10.3, Gallon 2013:B.2
WS50_1	Archaeological Site #1 Ku Bua	โบราณสถานหมายเลข 1 เมืองคูบัว	Archaeological Site	SAC

(table cont'd.)

Table D.1 continued

Site_ID	Name_English	Name_Thai	Site_Type	References
WS50_2	Archaeological Site #10 Ku Bua	โบราณสถานหมายเลข 10 เมืองคูบัว	Archaeological Site	SAC
WS50_3	Archaeological Site #40 Ku Bua	โบราณสถานหมายเลข 40 เมืองคูบัว	Archaeological Site	SAC
WS50_4	Archaeological Site #8 Ku Bua	โบราณสถานหมายเลข 8 เมืองคูบัว	Archaeological Site	SAC
WS50_5	Archaeological Site #31 Ku Bua	โบราณสถานหมายเลข 31 เมืองคูบัว (โคกวิหาร)	RP-Chedi Base	FAD
WS50_6	Archaeological Site #33 Ku Bua	โบราณสถานหมายเลข 33 เมืองคูบัว (โคกนายพร้อม)	RP-Chedi Base	FAD
WS50_7	Archaeological Site #44 Ku Bua	โบราณสถานหมายเลข 44 เมืองคูบัว(โคกประดิษฐ์อิฐ/โคกนายผาด)	RP-Chedi	FAD, SAC
WS50_8	Wat Khlong Suwankhiri	โบราณสถานหมายเลข 18 เมืองคูบัว (วัดโขลงสุวรรณคีรี)	Archaeological Site	FAD
WS51	Khao Wang Sadung	เขาวังสะดึง	Ancient Community	Pisnupong 1999
WS52	Ban Khok Prik	เมืองโคกพริก	Ancient Town	Pisnupong 1999
WS53	Wat Kao	ชุมชนโบราณวัดเกาะ	Ancient Community	Pisnupong 1999
WS54	Wat Khunsi	ชุมชนโบราณวัดขุนสีห์ (วัดท้าวอู่ทอง)	Ancient Community	Pisnupong 1999
WS55	Ban Wat Pa Kai	ชุมชนโบราณวัดป่าไก่	Ancient Community	Pisnupong 1999
WS56	Maung Weang Tun	เมืองเวียงทุน	Ancient Town	Pisnupong 1999
WS61	Cham Cave	ถ้ำจาม	AS-Cave/Shelter	SAC
WS62	Chin Cave	ถ้ำจีน	AS-Cave/Shelter	SAC
WS63	Pha Tho Cave	ถ้ำฝาโถ	AS-Cave/Shelter	SAC
WS64	Rusi Cave	ถ้ำฤๅษี	AS-Cave/Shelter	SAC
WS9	Wong Khong	วังฆ้อง	AS-Artifacts Found	FAD

Table D.2: Site Locations

Site_ID	District_ Th	Province _ Th	District_En	Province_ En	Longitude	Latitude
CS1	ไตรตรึงษ์	กำแพงเพชร	Trai Trueng	Kamphaeng Phet	99.566947	16.37325
CS10	สรรพยา	ชัยนาท	Sappaya	Chai Nat	100.204167	15.159722
CS100	เมือง	สมุทรสาคร	Muang	Samut SongKarm	100.391518	13.556622
CS101	บ้านหม้อ	สระบุรี	Ban Mo	Saraburi	100.735496	14.620666
CS102	หนองแซง	สระบุรี	Nong Saeng	Saraburi	100.838521	14.414445
CS103	แก่งคอย	สระบุรี	Kaeng Khoi	Saraburi	101.145448	14.575366
CS104	พระพุทธบาท	สระบุรี	Pra Buddhabat	Saraburi	100.828854	14.672136
CS105	อินทร์บุรี	สิงห์บุรี	In Buri	Sing Buri	100.277729	14.994263
CS106	บางระจัน	สิงห์บุรี	Bang Rachan	Sing Buri	100.238889	14.869444
CS107	บางระจัน	สิงห์บุรี	Bang Rachan	Sing Buri	100.218333	14.949722
CS108	ศรีสัชนาลัย	สุโขทัย	Si Satchanalai	Sukhothai	99.805957	17.428304
CS109	ศรีสัชนาลัย	สุโขทัย	Si Satchanalai	Sukhothai	99.785728	17.432042
CS11	ตาคลี	นครสวรรค์	Takhli	Nakhon Sawan	100.254167	15.313333
CS111	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.873111	14.383439
CS112	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.860684	14.471053
CS113	เมือง	สุพรรณบุรี	Muang	Suphan Buri	100.094127	14.474626
CS114	เดิมบางนางบวช	สุพรรณบุรี	Duembang Nangbuat	Suphan Buri	100.213368	14.852079
CS115	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.916667	14.244444
CS116	ดอนเจดีย์	สุพรรณบุรี	Don Chedi	Suphan Buri	100.03	14.68
CS117	เมือง	สุพรรณบุรี	Muang	Suphan Buri	99.95	14.58
CS118	เมือง	สุพรรณบุรี	Muang	Suphan Buri	99.97	14.57
CS119	หนองหญ้าไซ	สุพรรณบุรี	Nong Ya Sai	Suphan Buri	99.912876	14.776055
CS12	เมือง	นครนายก	Muang	Nakhon Nayok	101.16669	14.153458
CS120	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.854424	14.352625
CS121	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.9	14.36
CS122	ดอนเจดีย์	สุพรรณบุรี	Don Chedi	Suphan Buri	99.908247	14.765173
CS123	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.888239	14.37091
CS124	ดอนเจดีย์	สุพรรณบุรี	Don Chedi	Suphan Buri	99.925	14.610556

(table cont'd.)

Table D.2 continued

Site_ ID	District _ Th	Province _ Th	District_ En	Province_ En	Longitude	Latitude
CS125	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.909803	14.42901
CS126	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.959722	14.244444
CS127	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.9	14.366667
CS128	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.9	14.35
CS129	อู่ทอง	สุพรรณบุรี	U Thong	Suphan Buri	99.861111	14.324444
CS13	ปากพลี	นครนายก	Pak Pli	Nakhon Nayok	101.290723	14.112514
CS130	แสวงหา	อ่างทอง	Sawaengha	Ang Thong	100.311039	14.786138
CS132	เมือง	อุทัยธานี	Muang	Uthai Thani	100.012073	15.382707
CS133	สว่างอารมณ์	อุทัยธานี	Sawang Arom	Uthai Thani	99.710916	15.63304
CS134	บ้านไร่	อุทัยธานี	Ban Rai	Uthai Thani	99.699643	15.178711
CS135	เมือง	อุทัยธานี	Muang	Uthai Thani	100.038889	15.338333
CS136	เมือง	อุทัยธานี	Muang	Uthai Thani	100.029167	15.504167
CS137	หนองขาหย่าง	อุทัยธานี	Nong Khayang	Uthai Thani	99.90888889	15.31083333
CS138	หนองขาหย่าง	อุทัยธานี	Nong Khayang	Uthai Thani	100.031389	15.302778
CS14	เมือง	นครปฐม	Muang	Nakhon Pathom	100.060574	13.819575
CS15	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09695	13.814939
CS16	เมือง	นครปฐม	Muang	Nakhon Pathom	100.1	13.85
CS17	เมือง	นครปฐม	Muang	Nakhon Pathom	100.07	13.84
CS18	เมือง	นครปฐม	Muang	Nakhon Pathom	100.12	13.81
CS19	เมือง	นครปฐม	Muang	Nakhon Pathom	100.11	13.82
CS2	สรรค์บุรี	ชัยนาท	Sankhaburi	Chai Nat	100.157542	15.001139
CS20	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09	13.81
CS21	เมือง	นครปฐม	Muang	Nakhon Pathom	100.055108	13.822997
CS22	เมือง	นครปฐม	Muang	Nakhon Pathom	100.12	13.8
CS23	เมือง	นครปฐม	Muang	Nakhon Pathom	100.11	13.8

(table cont’d.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
CS24	เมือง	นครปฐม	Muang	Nakhon Pathom	100.06	13.8
CS25	เมือง	นครปฐม	Muang	Nakhon Pathom	100.11	13.8
CS26	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09	13.84
CS27	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09	13.82
CS28	เมือง	นครปฐม	Muang	Nakhon Pathom	100.11	13.82
CS29	เมือง	นครปฐม	Muang	Nakhon Pathom	100.06	13.82
CS3	มโนรมย์	ชัยนาท	Manorom	Chai Nat	100.172637	15.275873
CS30	เมือง	นครปฐม	Muang	Nakhon Pathom	100.087689	13.831556
CS31	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09886	13.815863
CS32	เมือง	นครปฐม	Muang	Nakhon Pathom	100.08	13.8
CS33	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09	13.81
CS34	เมือง	นครปฐม	Muang	Nakhon Pathom	100.064004	13.81964
CS35	เมือง	นครปฐม	Muang	Nakhon Pathom	99.91	13.85
CS36	เมือง	นครปฐม	Muang	Nakhon Pathom	100.079918	13.798321
CS37	เมือง	นครปฐม	Muang	Nakhon Pathom	100.086642	13.744868
CS38	เมือง	นครปฐม	Muang	Nakhon Pathom	100.114713	13.812094
CS39	เมือง	นครปฐม	Muang	Nakhon Pathom	100.067155	13.811339
CS4	สรรค์บุรี	ชัยนาท	Sankhaburi	Chai Nat	100.152781	15.017578
CS40	เมือง	นครปฐม	Muang	Nakhon Pathom	100.055213	13.822929
CS41	เมือง	นครปฐม	Muang	Nakhon Pathom	100.09695	13.814936
CS42	ดอนตูม	นครปฐม	Don Tum	Nakhon Pathom	100.07	13.94
CS43	นครชัยศรี	นครปฐม	Nakhon Chai Si	Nakhon Pathom	100.12	13.79
CS44	นครชัยศรี	นครปฐม	Nakhon Chai Si	Nakhon Pathom	100.187067	13.816902
CS45	นครชัยศรี	นครปฐม	Nakhon Chai Si	Nakhon Pathom	100.13	13.8
CS46	นครชัยศรี	นครปฐม	Nakhon Chai Si	Nakhon Pathom	100.11	13.75
CS47	นครชัยศรี	นครปฐม	Nakhon Chai Si	Nakhon Pathom	100.13	13.79
CS48	กำแพงแสน	นครปฐม	Kampaeng Saen	Nakhon Pathom	99.962358	13.990328
CS49	เมือง	นครปฐม	Muang	Nakhon Pathom	100.096802	13.812974

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
CS5	เมือง	ชัยนาท	Muang	Chai Nat	100.163889	15.223611
CS50	เมือง	นครปฐม	Muang	Nakhon Pathom	100.080833	13.741944
CS53	ไพศาลี	นครสวรรค์	Phaisali	Nakhon Sawan	100.718956	15.575385
CS54	ไพศาลี	นครสวรรค์	Phaisali	Nakhon Sawan	100.692863	15.624325
CS55	ตาคลี	นครสวรรค์	Takhli	Nakhon Sawan	100.452249	15.116353
CS56	ท่าตะโก	นครสวรรค์	Tha Tako	Nakhon Sawan	100.500473	15.639689
CS57	พยุหะคีรี	นครสวรรค์	Phayuha Khiri	Nakhon Sawan	100.143442	15.41906
CS58	เมือง	นครสวรรค์	Muang	Nakhon Sawan	100.023714	15.704654
CS59	พยุหะคีรี	นครสวรรค์	Phayuha Khiri	Nakhon Sawan	100.264159	15.439096
CS6	มโนรมย์	ชัยนาท	Manorom	Chai Nat	100.22	15.295556
CS60	บรรพตพิสัย	นครสวรรค์	Banphot Phisai	Nakhon Sawan	100.007943	16.015523
CS61	ตาคลี	นครสวรรค์	Takhli	Nakhon Sawan	100.523611	15.25
CS62	ท่าตะโก	นครสวรรค์	Tha Tako	Nakhon Sawan	100.408611	15.606944
CS63	ท่าตะโก	นครสวรรค์	Tha Tako	Nakhon Sawan	100.453889	15.595833
CS64	พระนครศรีอยุธยา	พระนครศรีอยุธยา	Phra Nakhon Si Ayutthaya	Phra Nakhon Si Ayutthaya	100.573623	14.346769
CS65	ทับคล้อ	พิจิตร	Thap Khlo	Phichit	100.58	16.18
CS66	ทับคล้อ	พิจิตร	Thap Khlo	Phichit	100.633056	16.226944
CS67	ทับคล้อ	พิจิตร	Thap Khlo	Phichit	100.630385	16.228347
CS68	เนินมะปราง	พิษณุโลก	Noen Maprang	Phitsanulok	100.663783	16.688627
CS69	เนินมะปราง	พิษณุโลก	Noen Maprang	Phitsanulok	100.82	16.66
CS7	สรรค์บุรี	ชัยนาท	Sankhaburi	Chai Nat	100.15	15.016667
CS70	เนินมะปราง	พิษณุโลก	Noen Maprang	Phitsanulok	100.66	16.69
CS71	เนินมะปราง	พิษณุโลก	Noen Maprang	Phitsanulok	100.691268	16.681297

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
CS72	เนินมะปราง	พิษณุโลก	Noen Maprang	Phitsanulok	100.653945	16.666807
CS73	นครไทย	พิษณุโลก	Nakhon Thai	Phitsanulok	100.839316	17.103181
CS74	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.144	15.467
CS74_1	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.144522	15.487098
CS74_2	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.156762	15.485951
CS74_3	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.144684	15.465584
CS74_4	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.145329	15.466254
CS77	ศรีเทพ	เพชรบูรณ์	Si Thep	Phetchabun	101.143996	15.465936
CS8	สรรค์บุรี	ชัยนาท	Sankhaburi	Chai Nat	100.226389	15.0375
CS80	เมือง	ลพบุรี	Muang	Lop Buri	100.62	14.79
CS81	เมือง	ลพบุรี	Muang	Lop Buri	100.615071	14.801307
CS82	เมือง	ลพบุรี	Muang	Lop Buri	100.609562	14.803292
CS83	เมือง	ลพบุรี	Muang	Lop Buri	100.6175	14.011111
CS84	ลำสนธิ	ลพบุรี	Lam Sonthi	Lop Buri	101.39	15.13
CS85	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.657275	15.596996
CS86	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.6189	14.99296
CS87	บ้านหมี่	ลพบุรี	Ban Mi	Lop Buri	100.871133	15.145215
CS88	ชัยบาดาล	ลพบุรี	Chai Badan	Lop Buri	101.030941	15.201156
CS89	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.855048	15.131362
CS9	สรรค์บุรี	ชัยนาท	Sankhaburi	Chai Nat	100.137222	14.981389
CS91	ท่าหลวง	ลพบุรี	Tha Luang	Lop Buri	101.240005	15.052407
CS93	เมือง	ลพบุรี	Muang	Lop Buri	100.6125	14.911111
CS94	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.727222	15.068611
CS95	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.76222	15.022778
CS96	โคกสำโรง	ลพบุรี	Khok Samrong	Lop Buri	100.85	15.133333
CS97	บ้านหมี่	ลพบุรี	Ban Mi	Lop Buri	100.530556	14.966667
CS98	เมือง	ลพบุรี	Muang	Lop Buri	100.617778	14.798056

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
CS99	เมือง	สมุทรสาคร	Muang	Samut SongKarm	100.34	13.53
ES1	เมือง	จันทบุรี	Muang	Chanthaburi	102.14	12.51
ES10	เมือง	ชลบุรี	Muang	Chon Buri	101.055556	13.427778
ES11	เมือง	ชลบุรี	Muang	Chon Buri	101.030556	13.413889
ES12	เมือง	ชลบุรี	Muang	Chon Buri	101.052778	13.425
ES13	เมือง	ชลบุรี	Muang	Chon Buri	101.036111	13.416667
ES14	บ่อทอง	ชลบุรี	Bo Thong	Chon Buri	101.433333	13.25
ES15	พานทอง	ชลบุรี	Pan Thong	Chon Buri	101.075	13.422222
ES2	พนมสารคาม	ฉะเชิงเทรา	Phanom Sarakham	Chachoengsao	101.3645	13.72484
ES28	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.414033	13.89458
ES28_1	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.42	13.9
ES28_10	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.411412	13.889655
ES28_13	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_11	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.86
ES28_14	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri		
ES28_12	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_15	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_16	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_17	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_18	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_19	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_2	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.42	13.89
ES28_3	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.406875	13.89472
ES28_4	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.42	13.9
ES28_5	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES28_6	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.42	13.89
ES28_7	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.41	13.89
ES28_8	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.41	13.89
ES28_9	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.431009	13.860234
ES28_20	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.43	13.9
ES29	กบินทร์บุรี	ปราจีนบุรี	Kabin Buri	Prachin Buri	101.808333	13.791667

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
ES3	แปลงยาว	ฉะเชิงเทรา	Plaeng Yao	Chachoengsao	101.274167	13.6
ES30	กบินทร์บุรี	ปราจีนบุรี	Kabin Buri	Prachin Buri	101.816667	13.806667
ES31	วัฒนานคร	ปราจีนบุรี	Wattananakorn	Prachin Buri	102.3	13.705833
ES32	ศรีมโหสถ	ปราจีนบุรี	Si Mahosot	Prachin Buri	101.426143	13.863248
ES33	ศรีมหาโพธิ	ปราจีนบุรี	Si Maha Phot	Prachin Buri	100.493611	13.945556
ES34	ศรีมหาโพธิ	ปราจีนบุรี	Si Maha Phot	Prachin Buri	101.204444	13.909722
ES35	ศรีมหาโพธิ	ปราจีนบุรี	Si Maha Phot	Prachin Buri	101.500556	13.949167
ES36	ศรีมหาโพธิ	ปราจีนบุรี	Si Maha Phot	Prachin Buri	101.504444	13.956667
ES37	อรัญประเทศ	สระแก้ว	Aranyaprathet	Sa Kaeo	102.439722	13.684722
ES38	อรัญประเทศ	สระแก้ว	Aranyaprathet	Sa Kaeo	102.52723	13.584047
ES39	อรัญประเทศ	สระแก้ว	Aranyaprathet	Sa Kaeo	102.43411	13.682402
ES4	พนมสารคาม	ฉะเชิงเทรา	Phanom Sarakham	Chachoengsao	101.380556	13.772222
ES40	เขาฉกรรจ์	สระแก้ว	Khao Chakan	Sa Kaeo	102.088889	13.659722
ES41	เมือง	สระแก้ว	Muang	Sa Kaeo	102.173333	13.728611
ES42	อรัญประเทศ	สระแก้ว	Aranyaprathet	Sa Kaeo	102.445833	13.806667
ES43	เมือง	สระแก้ว	Muang	Sa Kaeo	102.1444444	13.7425
ES5	พนมสารคาม	ฉะเชิงเทรา	Phanom Sarakham	Chachoengsao	101.150833	13.663333
ES6	พนมสารคาม	ฉะเชิงเทรา	Phanom Sarakham	Chachoengsao	101.330143	13.67608
ES7	พนัสนิคม	ชลบุรี	Panat Nikhom	Chon Buri	101.167295	13.465382
ES8	เมือง	ชลบุรี	Muang	Chon Buri	101.055556	13.427778
ES9	เมือง	ชลบุรี	Muang	Chon Buri	101.038889	13.427778
NS1	เมือง	ลำพูน	Muang	Lamphun	99.007875	18.577286
L1	กมลาสัย	กาฬสินธุ์	Kamalasai	Kalasin	103.518611	16.315278
L10	คำเขื่อนแก้ว	ยโสธร	Kham Khuen Kaeo	Yasothon	104.251389	15.646944
L100	เมือง	กาฬสินธุ์	Muang	Kalasin	103.509167	16.640833
L101	สตึก	บุรีรัมย์	Satuk	Buriram	103.396667	15.2525
L102	สว่างแดนดิน	สกลนคร	Sawan Deang Din	Sakon Nakon	103.558611	17.483056
L103	กุดบาก	สกลนคร	Kut Bak	Sakon Nakon	103.9025	17.101111

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	
L104	พรรณานิคม	สกลนคร	Phanna Nikhom	Sakon Nakon	103.835833	17.163333
L105	ท่าบ่อ	หนองคาย	Tha Bo	Nong Khai	102.504444	17.786389
L106	กิ่งอำเภอรัตนวาปี	หนองคาย	Minor District Rattana Wapi	Nong Khai	103.208282	18.26669
L107	ศรีธาตุ	อุดรธานี	Sri That	Udon Thani	103.245278	17.018611
L108	กิ่งอำเภอกู่แก้ว	อุดรธานี	Minor District Ku Kaeo	Udon Thani	103.098056	17.204722
L109	เขื่องใน	อุบลราชธานี	Khuang Nai	Ubon Ratchathani	104.438889	15.464167
L11	มหาชนะชัย	ยโสธร	Maha Chana Chai	Yasothon	104.189722	15.536944
L110	หนองวัวซอ	อุดรธานี	Nong Wow Sor	Udon Thani	102.581667	17.111944
L111	ศรีขรภูมิ	สุรินทร์	Sikhoraphum	Surin	103.854167	15.021944
L12	มหาชนะชัย	ยโสธร	Maha Chana Chai	Yasothon	104.3375	15.520556
L13	คำเขื่อนแก้ว	ยโสธร	Kham Khuen Kaeo	Yasothon	104.376944	15.681389
L14	เมือง	ยโสธร	Muang	Yasothon	104.166944	15.826111
L15	เมือง	ยโสธร	Muang	Yasothon	104.219444	15.723056
L16	ชุมแพ	ขอนแก่น	Chum Pae	Khon Kaen	102.200556	16.525833
L17	ชุมแพ	ขอนแก่น	Chum Pae	Khon Kaen	102.218333	16.850833
L18	กิ่งอำเภอโคกโพธิ์ไชย	ขอนแก่น	Minor District Khok Pho Chai	Khon Kaen	102.367778	16.029167
L19	บ้านไผ่	ขอนแก่น	Ban Phai	Khon Kaen	102.659444	16.077222
L2	สหัสขันธ์	กาฬสินธุ์	Sahat Sakhan	Kalasin	103.599722	16.738333
L20	ชุมแพ	ขอนแก่น	Chum Pae	Khon Kaen	102.019722	16.6975
L21	ชุมแพ	ขอนแก่น	Chum Pae	Khon Kaen	102.416111	16.678611
L22	เกษตรสมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyapoom	101.978611	16.236389
L23	เกษตรสมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyapoom	101.929444	16.242222
L24	เกษตรสมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyapoom	101.978611	16.236389
L25	เกษตรสมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyapoom	101.9725	16.352222
L26	เกษตรสมบูรณ์	ชัยภูมิ	Muang	Chaiyapoom	102.1325	15.786667

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province _ Th	District_ En	Province_ En	Longitude	Latitude
L27	บ้านเขว้า	ชัยภูมิ	Ban Khao	Chaiyapoom	101.945556	15.7225
L28	จัตุรัส	ชัยภูมิ	Chutturat	Chaiyapoom	101.841111	15.563611
L29	เมือง	ชัยภูมิ	Muang	Chaiyapoom	102.034722	15.808333
L3	กุฉินารายณ์	กาฬสินธุ์	Kuchinarai	Kalasin	104.100833	16.562778
L30	เกษตรสมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyapoom	101.909722	16.280278
L31	ภูเขียว	ชัยภูมิ	Phu Khiao	Chaiyapoom	102.039444	16.409722
L32	คอนสวรรค์	ชัยภูมิ	Korn Sawan	Chaiyapoom	102.327222	15.943333
L33	เสลภูมิ	ร้อยเอ็ด	Selaphum	Roi Et	104.020833	16.116944
L34	พนมไพร	ร้อยเอ็ด	Phanom Phrai	Roi Et	104.114444	15.678611
L35	เมือง	ร้อยเอ็ด	Muang	Roi Et	103.65	16.036389
L36	นาดูน	มหาสารคาม	Na Dun	Mahasarakham	103.271111	15.722222
L37	กันทรวิชัย	มหาสารคาม	Kantharawichai	Mahasarakham	103.299722	16.307222
L38	เมือง	มหาสารคาม	Muang	Mahasarakham	103.3725	16.154167
L39	ลืออำนาจ	อำนาจเจริญ	Lue Amnat	Amnat Chareon	104.688056	15.683611
L4	เขาวง	กาฬสินธุ์	Khao Wong	Kalasin	103.990278	16.791667
L40	หัวตะพาน	อำนาจเจริญ	Hua Taphan	Amnat Chareon	104.735	15.935556
L41	เมือง	อำนาจเจริญ	Muang	Amnat Chareon	104.503611	15.950278
L42	ม่วงสามสิบ	อุบลราชธานี	Muang Samsip	Ubon Ratchathani	104.725833	15.512222
L43	พนา	อำนาจเจริญ	Phana	Amnat Chareon	105.006667	15.941944
L44	ประโคนชัย	บุรีรัมย์	Prakorn Chai	Buriram	103.0575	14.781389
L45	นางรอง(ปะคำ)	บุรีรัมย์	Brakum	Buriram	102.716667	14.5525
L46	หนองหงส์	บุรีรัมย์	Nong Hong	Buriram	102.754444	15.034444
L47	คูเมือง	บุรีรัมย์	Khu Muang	Buriram	103.0375	15.392778
L48	ประโคนชัย	บุรีรัมย์	Prakorn Chai	Buriram	102.849444	14.548611
L49	สูงเนิน	นครราชสีมา	Sung Noen	Nakorn Ratchasima	101.796389	14.920833
L5	นามน	กาฬสินธุ์	Na Mon	Kalasin	103.824722	16.571667
L50	โนนสูง	นครราชสีมา	Non Sung	Nakorn Ratchasima	102.285278	15.089167
L51	ราษีไศล	ศรีสะเกษ	Rasi Salai	Sri Saket	104.174444	15.354167

(table cont'd.)

Table D.2 continued

Site_ ID	District _ Th	Province _ Th	District_ En	Province_ En	Longitude	Latitude
L52	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.400556	17.714167
L53	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.501944	17.7375
L54	สว่างแดนดิน	สกลนคร	Sawan Deang Din	Sakon Nakon	103.566111	17.441944
L55	วังสะพุง	เลย	Wang Sapung	Loei	101.768889	17.298889
L56	ธาตุพนม	นครพนม	That Panom	Nakorn Panom	104.723611	16.942222
L57	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.361667	17.730833
L58	หนองหาน	อุดรธานี	Nong Hahn	Udon Thani	103.219444	17.358056
L59	หนองหาน	อุดรธานี	Nong Hahn	Udon Thani	103.105833	17.359444
L6	กุฉินารายณ์	กาฬสินธุ์	Kuchinarai	Kalasin	104.100833	16.562778
L60	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.358889	17.660556
L61	ศรีเชียงใหม่	หนองคาย	Sri Chiang Mai	Nong Khai	102.427222	17.981944
L62	นากลาง	หนองบัวลำภู	Na Glang	Nong Bua Lampoo	102.185278	17.285
L63	เมือง	สกลนคร	Muang	Sakon Nakon	104.373889	17.261389
L64	น้ำพอง	ขอนแก่น	Nam Phong	Khon Kaen	102.879167	16.619722
L65	เมือง	ขอนแก่น	Muang	Khon Kaen	102.816944	16.433611
L66	พยัคฆภูมิพิสัย	มหาสารคาม	Phayakkaphum Phisai	Mahasarakham	103.385556	15.511389
L67	หนองหาน (กิ่งอำเภอกู่แก้ว)	อุดรธานี		Udon Thani	103.108333	17.203889
L68	เมือง	สกลนคร	Nong Hahn	Sakon Nakon	104.107778	17.151389
L69	ครบุรี	นครราชสีมา	Khonburi	Nakorn Ratchasima	102.102222	14.360833
L7	กุมภวาปี	อุดรธานี	Kumphawapi	Udon Thani	103.017778	17.135664
L70	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.388056	17.634167
L71	เต่างอย	สกลนคร	Tao Gnoi	Sakon Nakon	104.184444	16.992778
L72	อากาศอำนวย	สกลนคร	Akat Amnuai	Sakon Nakon	103.951389	17.521389
L73	ทรายมูล	ยโสธร	Sai Mun	Yasothon	104.289444	15.909722
L74	เมือง	กาฬสินธุ์	Muang	Kalasin	NA	NA

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
L8	เมือง	ยโสธร	Muang	Yasothon	104.147778	15.795833
L9	เมือง	ยโสธร	Muang	Yasothon	104.319722	15.980556
L93	สว่างแดนดิน	สกลนคร	Sawan Deang Din	Sakon Nakon	103.855556	17.355833
L94	เขื่องใน	อุบลราชธานี	Khuang Nai	Ubon Ratchathani	104.520556	15.388333
L95	ธาตุพนม	นครพนม	That Panom	Nakorn Panom	104.724444	16.991111
L96	ธาตุพนม	นครพนม	That Panom	Nakorn Panom	104.676667	16.928611
L97	ธาตุพนม	นครพนม	That Panom	Nakorn Panom	104.709444	16.911111
L98	ธาตุพนม	นครพนม	That Panom	Nakorn Panom	104.703611	16.876389
L99	เมือง	หนองคาย	Muang	Nong Khai	102.668056	16.799722
NES1	กมลาไสย	กาฬสินธุ์	Kamalasai	Kalasin	103.518882	16.314994
NES10	ฆ้องชัย พัฒนา	กาฬสินธุ์	Khong Chai Phattana	Kalasin	103.520253	16.31908
NES11	สหัสขันธ์	กาฬสินธุ์	Kuchi Narai	Kalasin	103.57	16.73
NES12	อุ่มเม่า	กาฬสินธุ์	Yang Talat	Kalasin	103.42733	16.389803
NES13	ชุมแพ	ขอนแก่น	Chum Phae	Khon Kaen	102.003189	16.593785
NES14	พระยืน	ขอนแก่น	Phra Yuen	Khon Kaen	102.636134	16.357989
NES15	ภูเวียง	ขอนแก่น	Phu Wiang	Khon Kaen	102.47	16.61
NES16	พล	ขอนแก่น	Phon	Khon Kaen	102.56	15.82
NES17	ภูเวียง	ขอนแก่น	Phu Wiang	Khon Kaen	102.292222	16.725278
NES18	แวงใหญ่	ขอนแก่น	Waeng Yai	Khon Kaen	102.426306	15.879025
NES19	ชุมแพ	ขอนแก่น	Chum Phae	Khon Kaen	102.097412	16.514768
NES2	เมือง	กาฬสินธุ์	Muang	Kalasin	103.626453	16.62389
NES20	หนองเรือ	ขอนแก่น	Nong Ruea	Khon Kaen	102.38	16.49
NES21	เมือง	ชัยภูมิ	Muang	Chaiyaphum	102.060655	15.916102
NES22	เมือง	ชัยภูมิ	Muang	Chaiyaphum	102.041353	15.803728
NES23	เกษตร สมบูรณ์	ชัยภูมิ	Kaset Sombun	Chaiyaphum	101.97	16.27
NES24	เมือง	ชัยภูมิ	Muang	Chaiyaphum	102.031539	15.806359

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
NES25	ธาตุพนม	นครพนม	That Choeng Chum	Nakhon Phanom	104.72	16.91
NES26	ธาตุพนม	นครพนม	That Phanom	Nakhon Phanom	104.72385	16.94241
NES27	ธาตุพนม	นครพนม	That Phanom	Nakhon Phanom	104.723906	16.942586
NES28	พิมาย	นครราชสีมา	Phimai	Nakhon Ratchasima	102.511289	15.219549
NES29	โนนสูง	นครราชสีมา	Non Sung	Nakhon Ratchasima	102.365993	15.25968
NES3	เมือง	กาฬสินธุ์	Muang	Kalasin	103.502061	16.437587
NES30	สีคิ้ว	นครราชสีมา	Sikhio	Nakhon Ratchasima	101.67604	14.85672
NES31	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.798266	14.921792
NES31_1	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79832	14.922
NES31_2	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79832	14.922
NES31_3	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79938	14.92284
NES31_4	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79987	14.92218
NES31_5	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79987	14.92218
NES31_6	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79736	14.92531
NES31_7	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.79693	14.9251
NES39	สูงเนิน	นครราชสีมา	Sung Noen	Nakhon Ratchasima	101.793399	14.916038
NES4	กมลาไสย	กาฬสินธุ์	Kamalasai	Kalasin	103.52	16.31
NES40	หนองหงส์	บุรีรัมย์	Nong Hong	Buri Ram	102.737963	14.848612
NES41	พุทไธสง	บุรีรัมย์	Putthaisong	Buri Ram	103.002208	15.540843
NES42	เมือง	มหาสารคาม	Muang	Maha Sarakham	103.3	16.17
NES43	นาเชือก	มหาสารคาม	Na Chueak	Maha Sarakham	103.04	15.78

(table cont'd.)

Table D.2 continued

Site_ ID	District _ Th	Province _ Th	District_ En	Province_ En	Longitude	Latitude
NES44	นาเชือก	มหาสารคาม	Na Chueak	Maha Sarakham	103.05	15.74
NES45	นาเชือก	มหาสารคาม	Na Chueak	Maha Sarakham	103.029727	15.771464
NES46	นาดูน	มหาสารคาม	Na Dune	Maha Sarakham	103.255556	15.704444
NES47	กิ่งอำเภอนาดูน	มหาสารคาม	King Amphoe Na Dune	Maha Sarakham	103.274059	15.720454
NES48	กันทรวิชัย	มหาสารคาม	Kantharawichai	Maha Sarakham	103.30148	16.310934
NES49	นาดูน	มหาสารคาม	Na Dune	Maha Sarakham	103.227114	15.703254
NES5	กมลาไสย	กาฬสินธุ์	Kamalasai	Kalasin	103.53	16.3
NES50	นาดูน	มหาสารคาม	Na Dune	Maha Sarakham	103.227163	15.699631
NES51	คำเขื่อนแก้ว	ยโสธร	Kham Khuean Kaeo	Yasothon	104.258093	15.639933
NES52	ป่าติ้ว	ยโสธร	Pa Tio	Yasothon	104.37	15.77
NES53	เมือง	ยโสธร	Muang	Yasothon	104.201029	15.762317
NES55	หนองฮี	ร้อยเอ็ด	Nong Hi	Roi Et	103.940716	15.555815
NES56	เมือง	ร้อยเอ็ด	Muang	Roi Et	103.645871	16.061058
NES57	เมือง	ร้อยเอ็ด	Muang	Roi Et	103.648848	16.056415
NES58	เมือง	ร้อยเอ็ด	Muang	Roi Et	103.604834	16.003422
NES59	วังสะพุง	เลย	Wang Saphung	Loei	101.872778	17.238889
NES6	กมลาไสย	กาฬสินธุ์	Kamalasai	Kalasin	103.49	16.3
NES60	เชียงคาน	เลย	Chiang Khan	Loei	101.683407	17.904931
NES661	ราษีไศล	ศรีสะเกษ	Rasi Salai	Si Sa Ket	104.176422	15.353561
NES662	สว่างแดนดิน	สกลนคร	Sawang Daen Din	Sakon Nakhon	103.549968	17.44481
NES663	กุดบาก	สกลนคร	Kut Bak	Sakon Nakhon	103.95	17.14
NES664	เมือง	สกลนคร	Muang	Sakon Nakhon	104.242018	17.140596
NES665	ธาตุเชิงชุม	สกลนคร	That Choeng Chum	Sakon Nakhon	104.17	17.18
NES666	สว่างแดนดิน	สกลนคร	Sawang Daen Din	Sakon Nakhon	103.561053	17.441407

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
NES667	เต่างอย	สกลนคร	Tao Ngoi	Sakon Nakhon	104.14	16.99
NES668	เต่างอย	สกลนคร	Tao Ngoi	Sakon Nakhon	104.1676448	16.9965815
NES669	เต่างอย	สกลนคร	Tao Ngoi	Sakon Nakhon	104.133157	16.975605
NES670	เมือง	สกลนคร	Muang	Sakon Nakhon	104.060958	17.061667
NES672	ท่าบ่อ	หนองคาย	Tha Bo	Nong Khai	102.638198	17.746305
NES674	สังคม	หนองคาย	Sangkhom	Nong Khai	102.279609	17.983452
NES675	นากลาง	หนองบัวลำภู	Na Klang	Nong Bua Lam Phu	102.187733	17.295846
NES676	ศรีบุญเรือง	หนองบัวลำภู	Si Bun Rueang	Nong Bua Lam Phu	102.200556	16.95
NES677	นากลาง	หนองบัวลำภู	Na Klang	Nong Khai	102.248333	17.246972
NES678	นากลาง	หนองบัวลำภู	Na Klang	Nong Khai	102.250139	17.246611
NES679	ศรีบุญเรือง	หนองบัวลำภู	Si Bun Rueang	Nong Khai	102.155556	16.8875
NES680	พนา	อำนาจเจริญ	Phana	Amnat Charoen	104.82	15.73
NES681	ลืออำนาจ	อำนาจเจริญ	Lue Amnat	Amnat Charoen	104.684333	15.6867
NES683	หัวตะพาน	อำนาจเจริญ	Hua Taphan	Amnat Charoen	104.592403	15.76015
NES685	บ้านดุง	อุดรธานี	Ban Dung	Udon Thani	103.321944	17.599722
NES686	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.34	17.56
NES687	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.348417	17.671056
NES688	เมือง	อุดรธานี	Muang	Udon Thani	102.71	17.39
NES689	ศรีธาตุ	อุดรธานี	Si That	Udon Thani	103.27	16.98
NES690	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.35503	17.734884
NES691	เมือง	อุดรธานี	Muang	Udon Thani	102.745833	17.470833
NES692	กุดจับ	อุดรธานี	Kut Chap	Udon Thani	102.44	17.36
NES695	บ้านผือ	อุดรธานี	Ban Phue	Udon Thani	102.357848	17.73072
NES7	กุฉินารายณ์	กาฬสินธุ์	Kuchi Narai	Kalasin	104.1	16.55

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province_ Th	District_ En	Province_ En	Longitude	Latitude
NES8	กุฉินารายณ์	กาฬสินธุ์	Kuchi Narai	Kalasin	104.1	16.55
NES9	กุฉินารายณ์	กาฬสินธุ์	Kuchi Narai	Kalasin	104.05	16.54
SS4	ยะรัง	ปัตตานี	Yarang	Pattani	101.303576	6.765321
SS5	ยะรัง	ปัตตานี	Yarang	Pattani	101.303938	6.771926
SS6	ยะรัง	ปัตตานี	Yarang	Pattani	101.302129	6.74706
SS7	ยะรัง	ปัตตานี	Yarang	Pattani	101.303595	6.760249
SS8	ยะรัง	ปัตตานี	Yarang	Pattani	101.307356	6.76067
WS1	ท่ามะกา	กาญจนบุรี	Tha Maka	Kanchanaburi	99.781798	13.892993
WS10	เขาย้อย	เพชรบุรี	Khao Yoi	Phetchaburi	99.783436	13.205607
WS12	เขาย้อย	เพชรบุรี	Khao Yoi	Phetchaburi	99.835645	13.166232
WS13	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.94	13.07
WS14	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.84	13.1
WS15	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.85	13.09
WS19	เขาย้อย	เพชรบุรี	Khao Yoi	Phetchaburi	99.788615	13.18606
WS2	เมือง	กาญจนบุรี	Muang	Kanchanaburi	99.405556	14.095278
WS20	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.795824	13.059815
WS21	เขาย้อย	เพชรบุรี	Khao Yoi	Phetchaburi	99.854444	13.091667
WS22	เขาย้อย	เพชรบุรี	Khao Yoi	Phetchaburi	99.918056	12.958333
WS23	เมือง	เพชรบุรี	Muang	Phetchaburi	99.955278	13.101944
WS24	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.854722	13.048333
WS25	บ้านลาด	เพชรบุรี	Ban Lard	Phetchaburi	99.930748	13.058289
WS26	ชะอำ	เพชรบุรี	Cha-am	Phetchaburi	99.957396	12.856337
WS27	ชะอำ	เพชรบุรี	Cha-am	Phetchaburi	99.954157	12.847421
WS28	ชะอำ	เพชรบุรี	Cha-am	Phetchaburi	99.95125	12.847003
WS29	ท่ายาง	เพชรบุรี	Tha Yang	Phetchaburi	99.911733	12.963052
WS3	สังขละบุรี	กาญจนบุรี	Sankhaburi	Kanchanaburi	98.617402	14.954551
WS30	ท่ายาง	เพชรบุรี	Tha Yang	Phetchaburi	99.947222	12.968056
WS31	ท่ายาง	เพชรบุรี	Tha Yang	Phetchaburi	99.94357	12.968813
WS32	ชะอำ	เพชรบุรี	Cha-am	Phetchaburi	99.957738	12.84915
WS33	ท่ายาง	เพชรบุรี	Tha Yang	Phetchaburi	100.006395	12.933198
WS34	เมือง	ราชบุรี	Muang	Ratchaburi	99.798317	13.543014

(table cont'd.)

Table D.2 continued

Site_ ID	District_ Th	Province _ Th	District_ En	Province_ En	Longitude	Latitude
WS35	เมือง	ราชบุรี	Muang	Ratchaburi	99.813861	13.546658
WS36	บางแพ	ราชบุรี	Bang Phae	Ratchaburi	99.901972	13.702906
WS37	เมือง	ราชบุรี	Muang	Ratchaburi	99.776706	13.575441
WS38	เมือง	ราชบุรี	Muang	Ratchaburi	99.666667	13.55
WS39	ปากท่อ	ราชบุรี	Pak Tho	Ratchaburi	99.83271	13.416195
WS40	เมือง	ราชบุรี	Muang	Ratchaburi	99.79	13.53
WS41	เมือง	ราชบุรี	Muang	Ratchaburi	99.829684	13.540415
WS43	เมือง	ราชบุรี	Muang	Ratchaburi	99.79	13.53
WS44	ดำเนินสะดวก	ราชบุรี	Damnoen Saduak	Ratchaburi	99.99	13.63
WS45	บ้านโป่ง	ราชบุรี	Ban Pong	Ratchaburi	99.816829	13.760098
WS46	ปากท่อ	ราชบุรี	Pak Tho	Ratchaburi	99.84	13.38
WS50	เมือง	ราชบุรี	Muang	Ratchaburi	99.834847	13.483222
WS50_1	เมือง	ราชบุรี	Muang	Ratchaburi	99.827242	13.494033
WS50_2	เมือง	ราชบุรี	Muang	Ratchaburi	99.828107	13.485278
WS50_3	เมือง	ราชบุรี	Muang	Ratchaburi	99.8386	13.474637
WS50_4	เมือง	ราชบุรี	Muang	Ratchaburi	99.831167	13.490725
WS50_5	วัดเพลง	ราชบุรี	Wat Phleng	Ratchaburi	99.85	13.48
WS50_6	วัดเพลง	ราชบุรี	Wat Phleng	Ratchaburi	99.85	13.48
WS50_7	วัดเพลง	ราชบุรี	Wat Phleng	Ratchaburi	99.840586	13.468871
WS50_8	เมือง	ราชบุรี	Muang	Ratchaburi	99.835859	13.486412
WS51	เมือง	ราชบุรี	Muang	Ratchaburi	99.777778	13.6125
WS52	เมือง	ราชบุรี	Muang	Ratchaburi	99.863333	13.505833
WS53	เมือง	ราชบุรี	Muang	Ratchaburi	99.833333	13.536944
WS54	บ้านโป่ง	ราชบุรี	Ban Pong	Ratchaburi	99.811111	13.754722
WS55	ปากท่อ	ราชบุรี	Pak Tho	Ratchaburi	99.833333	13.420833
WS56	วัดเพลง	ราชบุรี	Wat Phleng	Ratchaburi	99.865	13.488611
WS61	เมือง	ราชบุรี	Muang	Ratchaburi	99.772916	13.574289
WS62	เมือง	ราชบุรี	Muang	Ratchaburi	99.772916	13.574289
WS63	เมือง	ราชบุรี	Muang	Ratchaburi	99.774969	13.575687
WS64	เมือง	ราชบุรี	Muang	Ratchaburi	99.777294	13.574917
WS9	แก่งกระจาน	เพชรบุรี	Kaeng Krachan	Phetchaburi	99.65	12.81

Table D.3: Type of site and references
Note: In this research, sites were categorized into 9 major types: Ancient Community, Ancient Town, Archaeological Site, Mixed, Public Utilities, Religious Place, Residence, Sema Site, and Shipwreck Site.

Type of Site	References	# of Site	%
Ancient Community	Pisnupong 1999	41	9.65
	Pisnupong 1999, FAD	6	1.41
	Pisnupong 1999, Indrawooth 1999	2	0.47
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:1.1, Gallon 2013:B.3(Unmoated)	1	0.24
	Pisnupong 1999, SAC, FAD	4	0.94
	Pisnupong 1999, SAC, FAD, Gallon 2013:B.1(Unmoated)	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:9.1	1	0.24
	Total	**56**	**13.18**
Ancient Town	FAD	6	1.41
	Indrawooth 1999	2	0.47
	Indrawooth 1999, Gallon 2013:B.28	1	0.24
	Indrawooth 1999, Gallon 2013:B.29	1	0.24
	Indrawooth 1999, Gallon 2013:B.30	1	0.24
	Indrawooth 1999, Gallon 2013:B.31	1	0.24
	Indrawooth 1999, Gallon 2013:B.32	1	0.24
	Indrawooth 1999, Gallon 2013:B.34	1	0.24
	Indrawooth 1999, Gallon 2013:Table B.5-Unlocated	2	0.47
	Indrawooth 1999, Supajanya and Vanasin 1980:3.2, Gallon 2013:Table B.5-Unlocated	1	0.24
	Pisnupong 1999	12	2.82
	Pisnupong 1999, FAD	1	0.24
	Pisnupong 1999, FAD, SAC, Gallon 2013:B.27	1	0.24
	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:12.3, Gallon 2013:B.21	1	0.24
	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:13.2, Gallon 2013:B.6	1	0.24
	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:13.9, Gallon 2013:B.9	1	0.24

(table cont'd.)

Table D.3 continued

Type of Site	References	# of Site	%
Ancient Town	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.1, Gallon 2013:B.15	1	0.24
	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.2, Gallon 2013:B.12	1	0.24
	Pisnupong 1999, Indrawooth 1999, FAD, Supajanya and Vanasin 1980:16.3	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.11	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.13	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.16	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.18	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:B.20	1	0.24
	Pisnupong 1999, Indrawooth 1999, Gallon 2013:Table B.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, SAC, Mudar 1999, SAC, Supajanya and Vanasin 1980:11.2, Gallon 2013:B.23	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:10.3, Gallon 2013:B.2	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:11.1, Gallon 2013:B.22	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:11.6, Gallon 2013:TableB.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:12.1, Gallon 2013:TableB.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:14.1, Gallon 2013:B.10	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:15.2, Gallon 2013:B.8	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:16.4, Gallon 2013:Table B.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:3.1, Gallon 2013:B.7	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:3.3, Gallon 2013:B.17	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:4.2, Gallon 2013:B.26	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:5.1	1	0.24

(table cont'd.)

Table D.3 continued

Type of Site	References	# of Site	%
Ancient Town	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:6.1	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:7.2, Gallon 2013:B.4	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.10, Gallon 2013:Table B.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.2, Gallon 2013:B.14	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.7, Gallon 2013:B.19	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:8.9, Gallon 2013:Table B.5-Unlocated	1	0.24
	Pisnupong 1999, Indrawooth 1999, Supajanya and Vanasin 1980:9.2, Gallon 2013:B.25	1	0.24
	Pisnupong 1999, Indrawooth 2008,Supajanya and Vanasin 1980:7.3, Gallon 2013:B.5	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:11.4	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:14.3	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:2.1	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:3.4	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:4.3	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:8.3	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:8.5	1	0.24
	Pisnupong 1999, Supajanya and Vanasin 1980:8.6	1	0.24
	SAC	7	1.65
	Supajanya and Vanasin 1984(I):20-44/234, FAD	1	0.24
	Supajanya and Vanasin 1984(II):41-1/8, Gallon 2013:B.33	1	0.24
	Thammarungruang 2015	2	0.47
	Thammarungruang 2015, FAD, SAC	1	0.24
	Total	**83**	**19.53**

(table cont'd.)

Table D.3 continued

Type of Site	References	# of Site	%
Archaeological Site	FAD	69	16.24
	Indrawooth 1999	1	0.24
	Indrawooth 2008	1	0.24
	Indrawooth 2008, FAD	1	0.24
	Indrawooth 2008, Silapanth 2006	1	0.24
	SAC	21	4.94
	SAC, FAD	3	0.71
	Total	**97**	**22.82**
Mixed	FAD	6	1.41
	FAD, SAC	1	0.24
	Total	**7**	1.65
Public Utilities	FAD	10	2.34
	Total	**10**	**2.34**
Religious Place	FAD	35	8.24
	FAD, SAC	1	0.24
	SAC	4	0.94
	Total	**40**	**9.41**
Residence	FAD	1	0.24
	Total	**1**	**0.24**
Sema Site	FAD	35	8.24
	Murphy 2010:Table A1a, A1b	88	20.71
	Murphy 2010:Table A1a, A1b, FAD	3	0.71
	Murphy 2010:Table A1a, A1b, SAC,	2	0.47
	Total	**128**	**30.12**
Shipwreck Site	FAD	2	0.47
	SAC	1	0.24
	Total	**3**	0.71
Grand Total		**425**	**100**

Table D.4: 83 Ancient Towns and 56 Communities with total enclosed area in km^2, plan, and moats

Site_ID	Name_English	Area_ SqKm	Plan	Moat
CS1	Trai Trueng	NA	NA	NA
CS10	Bang Kra Buang	0.145	circular	Moated
CS101	Kheetkhin	0.251	square	Moated
CS102	Dong Muang	0.83	circular (inner), rectangular (outer)	Moated
CS103	Bodhisattva Cave	NA	NA	NA
CS104	Wat Khao Wong (Narai Cave)	NA	NA	NA
CS105	Ku Muang (Inburi)	0.465	polygonal	Moated
CS106	Ban Keem	0.1	oval	Moated
CS107	Ban Ku	0.8	square/rectangular	Moated
CS109	Si Satchanalai Historical Park	NA	NA	NA
CS11	Muang Nang Lek	0.08	rectangular	Moated
CS114	Ku Muang (Duembang Nangbuat)	0.172	square	Moated
CS115	Ban Don Yai Koi	NA	NA	NA
CS117	Ban Ning Bua	NA	NA	NA
CS118	Ban Nong Hin	NA	NA	NA
CS12	Dong Lakhon	0.265	semi-circular	Moated
CS122	Nong Sam Rong	0.5	oval	Moated
CS123	U Thong	0.963	irregular/oval	Moated
CS124	Ban Nhong Jang	NA	NA	NA
CS125	Ban Khok Samrong	NA	NA	NA
CS126	Ban Don Makuer	NA	NA	NA
CS127	Ban Tha Mung	NA	NA	NA
CS128	Ban Na Lao	NA	NA	NA
CS129	Ban Wang Yasai	0.1156	square	Moated
CS13	Ban Kok Kradon	NA	NA	Unmoated
CS130	Ku Muang (Ang Thong)	0.119	square	Moated
CS132	Ban Dai	0.84	irregular	Moated
CS133	Bung Khok Chang	1.226	circular	Moated
CS134	Muang Ka Rung	0.134	square	Moated
CS135	Ban Thathong	NA	NA	NA
CS136	Ban Pung Toei	NA	NA	NA

(table cont'd.)

Table D.4 continued

Site_ID	Name_English	Area_ SqKm	Plan	Moat
CS137	Tung Prajan (Ban Ku/ Ban Nai Ku)	0.396	rectangular	Moated
CS138	Ban Lumkao	NA	NA	NA
CS2	Sankhaburi	3.15	irregular	Moated
CS3	U Tapao	0.547	irregular	Moated
CS4	Dong Khon	0.275	oval/polygonal	Moated
CS48	Kamphaeng Saen	0.525	polygonal	Moated
CS49	Nakhon Pathom	6.594	semi-rectangular	Moated
CS5	Khao Kayai	NA	NA	Unmoated
CS50	Don Yai Hom	NA	NA	NA
CS52	Ku Muang	NA	NA	NA
CS53	Pra Kham	0.021	semi-rectangular	Moated
CS54	Aphaisali	0.102	circular	Moated
CS55	Chansen	0.438	polygonal	Moated
CS56	Don Kha	0.701	irregular	Moated
CS57	Muang Bon	0.605	circular	Moated
CS58	Thap Chumphol	0.043	circular	Moated
CS59	Muang Huai Duk	0.189	rectangular	Moated
CS6	Nakon Noi	0.0625	square	Moated
CS60	Dong Mae Nang Muang	0.536	polygonal	Moated
CS61	Ban Nongbuataklan	NA	NA	Moated
CS62	Ban Nongnean (1)	0.01	circular	Moated
CS63	Ban Huathanonklang	0.45	square	Moated
CS65	Tan Klor	NA	NA	NA
CS7	Ban Klong Muay	NA	NA	NA
CS74	Si Thep	4.692	irregular	Moated
CS8	Ban Nong Bua	NA	NA	NA
CS83	Ban Thakae	NA	NA	NA
CS85	Ban Mai Phaisali	0.16	circular	Moated
CS86	Promtin Tai	0.785	oval/polygonal	Moated
CS87	Wang Phai	NA	square	Moated
CS88	Chai Badan	NA	NA	NA
CS89	Dong Marum	0.39	rectangular	Moated
CS9	Ban Thung Krathin	NA	NA	NA
CS91	Sab Champa	0.613	irregular	Moated
CS93	Khao Pra Ngarm	NA	NA	NA

(table cont’d.)

Table D.4 continued

Site_ID	Name_English	Area_ SqKm	Plan	Moat
CS94	Muang Sing Kuyang	0.43	circular	Moated
CS95	Khao Rae	NA	NA	NA
CS96	Nean Makok	NA	NA	Moated
CS97	Ban Kern Krathin	NA	NA	Unmoated
CS98	Muang Lavo	1.292	oval/irregular	Moated
ES10	Nean Khun Yai	NA	NA	NA
ES11	Nean Ban Nai Tum	NA	NA	NA
ES12	Nean Samrong	NA	NA	NA
ES13	Ban Don Lang	NA	NA	NA
ES14	Praya Re	0.34	oval	Moated
ES15	Nean Suan Nai	NA	NA	NA
ES2	Ban Ku Muang	0.415	irregular	Moated
ES28	Si Mahosot	0.98	semi-rectangular	Moated
ES29	Khao Duan	NA	NA	NA
ES3	Ban Plaeng Yao	NA	NA	NA
ES30	Ban Doi Lampu	NA	NA	NA
ES31	Ban Hoi	0.5	circular	Moated
ES32	Ban Sa Morakot	NA	NA	NA
ES33	Kok Khang	NA	NA	Unmoated
ES34	Sa Tarod	NA	NA	NA
ES35	Sa Noi	NA	NA	NA
ES36	Sa Yai Lung	NA	NA	NA
ES37	Muang Phai	NA	oval	Moated
ES4	Ban Kok Hua Kao	NA	NA	NA
ES40	Khao Chakan	NA	NA	NA
ES41	Tha Kaserm (1)	NA	circular	Moated
ES42	Ban Han Sai	NA	rectangular	Moated
ES43	Tha Kaserm (2)	NA	circular	NA
ES5	Ban Sa Song Torn	NA	NA	NA
ES6	Bung Kra Jub	NA	NA	NA
ES7	Muang Phra Rot	0.934	semi-rectangular	Moated
ES8	Nean Koh Klang	NA	NA	NA
ES9	Nean Khun Dis	NA	NA	NA
NES1	Muang Fa Daed Song	1.546	irregular	Moated
NES24	Chaiyaphum	NA	destroyed	NA
NES26	Muang Nakhon Panom	NA	NA	NA
NES28	Muang Phimai	NA	NA	NA

(table cont'd.)

Table D.4 continued

Site_ID	Name_English	Area_ SqKm	Plan	Moat
NES29	Ban Prasart	NA	irregular	Moated
NES31	Muang Sema	3.953	irregular	Moated
NES40	Muang Fhai	NA	NA	NA
NES41	Putthai Song	1.623	irregular	Moated
NES47	Na Dune	3.11	irregular	Moated
NES48	Kantharawichai	1.952	irregular	Moated
NES50	Muang Nakon Jampasri	4.05	rectangular	Moated
NES51	Dong Muang Toei	1.9	irregular/oval	Moated
NES53	Ban Tat Thong	0.375	oval	Moated
NES661	Muang Khong Khok	3.14	circular	Moated
NES683	Muang Gyew	NA	NA	NA
NS1	Haripunjaya	NA	NA	NA
SS4	Ban Cha Le	NA	NA	NA
SS5	Ban Prawa	NA	NA	NA
SS6	Ban Wat	NA	NA	NA
SS7	Yarang	NA	NA	NA
WS1	Pong Tuk	NA	NA	Unmoated
WS2	Ban Tha Wi	NA	NA	NA
WS22	Ban Nongprong	NA	NA	Unmoated
WS23	Phetchaburi	1.61	irregular	Moated
WS24	Nean Pho Yai	NA	NA	Unmoated
WS25	Wat Papan	NA	NA	Unmoated
WS27	Thung Setti	NA	NA	Unmoated
WS29	Ban Khao Krachiu	NA	NA	Unmoated
WS3	Ban Wang Pato	NA	NA	NA
WS30	Ban Mai	NA	NA	Unmoated
WS31	Ban Mab Pla Khao	NA	NA	Unmoated
WS33	Ban Don Tao It	NA	NA	Unmoated
WS37	Khao Ngu Cave	NA	NA	NA
WS38	Wat Mahathat Woravihara	NA	NA	NA
WS50	Ku Bua	1.71	rectangular	Moated
WS51	Khao Wang Sadung	NA	NA	NA
WS52	Ban Khok Prik	NA	NA	Moated
WS53	Wat Kao	NA	NA	NA
WS54	Wat Khunsi	NA	NA	NA
WS55	Ban Wat Pa Kai	NA	NA	NA
WS56	Maung Weang Tun	NA	NA	NA

APPENDIX E

RELATIONSHIP BETWEEN DVĀRAVATĪ SITES AND SPATIAL VARIABLES

Note: Soil type: Af = Ferric Acrisols, Ag= Gleyic Acrisols, Ao= Orthic Acrisols, Gd= Dystric Gleysols, Ge= Eutric Gleysols, I= Lithosols, Je= Eutric Fluvisols, Jt= Thionic Fluvisols, Lc=Chromic Luvisols, Lg=Gleyic Luvisols, Nd= Dystric Nitosols, Vp=Pellic Vertisols

Name of river basin: BP = Bang Prakong, CP= Chao Phraya, C= Chi, MK= Mae Klong, M (NE) = Mekong (Northeast), M= Mun, N= Nan, PS= Pa Sak, PN= Pattani, PR= Phetchaburi, P= Ping, PC= Prachin Buri, PEC=Peninsula-East coast, SK= Sakae Krang, TC= Tha Chin, TS= Thole Sap, Y= Yom; Region: CP=Central Plain, E=East, N=North, NE=Northeast, S=South, W=West

Regional Level

Table E.1a-1: Data used for Chi-Square test, the relationship between types of geology and Dvāravatī sites in regional level

Geology Group	Central Plain	Other Regions	Grand Total
A	18	33	51
B	35	7	42
C	17	29	46
Grand Total	**70**	**69**	**139**

Table E.1a-2: Additional detail of Table E.1a-1

Geology Group	Geology Type	CP	Other Regions					Total	%
			E	N	NE	S	W		
A	Alluvial deposits	13	6	1	6			26	18.71
	Alluvial fan deposits	1						1	0.72
	Channel deposits	1						1	0.72
	Flood plain deposits		10					10	7.19
	Fluviatile deposits	3					10	13	9.35
B	Neo Geology Formation	35	1			4	2	42	30.22
C	Khao Khad Formation	2						2	1.44
	Khok Kruat Formation				2			2	1.44
	Maha Sarakham Formation				3			3	2.16
	Marine clay deposits		1					1	0.72
	Ngao Group						2	2	1.44
	No data	1	5				1	7	5.04
	Old beach ridged deposits						1	1	0.72
	Phu Thok Formation				2			2	1.44
	Pong Nam Ron Formation		1					1	0.72
	Ratburi Group	1					1	2	1.44
	Residual deposits	10	1					11	7.91
	Sub Bon Formation	2						2	1.44
	Terrace deposits	1	3		2			6	4.32
	Tidal clay deposits						4	4	2.88
	Total	**70**	**28**	**1**	**15**	**4**	**21**	**139**	**100**

Table E.1b-1: Data used for Chi-Square test, the relationship between types of soil and Dvāravatī sites in regional level

Soil Group	Central Plain	Other Regions	Grand Total
A	35	41	76
J	12	10	22
V	16		16
Others	7	18	25
Grand Total	**70**	**69**	**139**

Table E.1b-2: Additional detail of Table E.1b-1

Group	Soil	Central Plain	Other Regions					Total	%
			East	North	Northeast	South	West		
A	Af	6	1				3	10	7.19
	Ag	29	8		11	4	12	64	46.04
	Ao						2	2	1.44
J	Je	8		1			2	11	7.91
	Jt	4	7					11	7.91
V	Vp	16						16	11.51
Others	Gd				4			4	2.88
	Ge	1	7				1	9	6.47
	I	1						1	0.72
	Lc	1					1	2	1.44
	Lg	1						1	0.72
	Nd	3	5					8	5.76
	Total	**70**	**28**	**1**	**15**	**4**	**21**	**139**	**100**

Table E.1c-1: Data used for Chi-Square test, the relationship between distance to the closest river and Dvāravatī sites in regional level

Distance to Closest River(m)	Central Plain	Other Regions	Grand Total
1	13	18	31
2	4	4	8
5	13	21	34
10	14	20	34
>10	26	6	32
Grand Total	**70**	**69**	**139**

Table E.1c-2: Additional detail of Table E.1c-1

Group	Distance to Closest River(m)	Central Plain	Other Regions						%
			E	N	NE	S	W		
1	1 km	13	4	1	4	2	7	31	22.30
2	2 km	4	3			1		8	5.76
5	5 km	13	6		4	1	10	34	24.46
10	10 km	14	11		5		4	34	24.46
>10	15 km	14	4		1			19	13.67
	20 km	8			1			9	6.47
	25 km	1						1	0.72
	30 km	3						3	2.16
	Total	**70**	**28**	**1**	**15**	**4**	**21**	**139**	100

Table E.1d-1: Data used for Chi-Square test, the relationship between elevation and Dvāravatī sites in regional level

Elevation (m)	Central Plain	Other Regions	Grand Total
0-50	55	43	98
>51	15	26	41
Grand Total	**70**	**69**	**139**

Table E.1d-2: Additional detail of Table E.1d-1

Group	Elevation (m)		Other Regions					Total	%
		Central Plain	East	North	Northeast	South	West		
0-50	0-50	54	20			4	19	97	69.78
>50	51-100	14	7				1	22	15.83
	101-150	1	1		7			9	6.47
	151-200	1			7		1	9	6.47
	201-250				1			1	0.72
	251-300			1				1	0.72
	Total	**70**	**28**	**1**	**15**	**4**	**21**	**139**	**100**

River Basin Level

Table E.2a-1: Data used for Chi-Square test, the relationship between types of geology and Dvāravatī sites in river basin level

Geology Group	Bang Prakong	Chao Phraya	Mae Klong	Tha Chin	Others	Grand Total
A	11	10	5	3	22	51
B	2	15	4	16	5	42
C	5	9	6		26	46
Grand Total	**18**	**34**	**15**	**19**	**53**	**139**

Table E.2a-2: Additional detail of Table E.2a-1

G	Geology	BP	CP	MK	TC	Other River Basins												∑
						C	M (NE)	M	N	PS	PN	PR	P	PC	SK	TS	Y	
A	Alluvial deposits	1	6		3	1	1	4	1	2			1	2	1	3		26
	Alluvial fan deposits		1															1

(table cont'd.)

Table E.2a-2 continued

G	Geology	BP	CP	MK	TC	Other River Basins												∑
						C	M (NE)	M	N	PS	PN	PR	P	PC	SK	TS	Y	
A	Channel deposits														1			1
	Flood plain deposits	10																10
	Fluviatile deposits		3	5								5						13
B	Neo Geology Formation	2	15	4	16						4		1					42
C	Khao Khad Formation		1							1								2
	Khok Kruat Formation							2										2
	Maha Sarakham Formation					1		2										3
	Marine clay deposits	1																1
	Ngao Group											2						2
	No data	1		1						1				4				7
	Old beach ridged deposits			1														1
	Phu Thok Formation					1		1										2
	Pong Nam Ron Formation													1				1
	Ratburi Group			2														2
	Residual deposits	1	8												1		1	11

(table cont'd.)

Table E.2a-2 continued

G	Geology	BP	CP	MK	TC	Other River Basins												∑
						C	M (NE)	M	N	PS	PN	PR	P	PC	SK	TS	Y	
A	Sub Bon Formation									1					1			2
	Terrace deposits	2				2				1				1				6
	Tidal clay deposits			2								2						4
	Total	**18**	**34**	**15**	**19**	**5**	**1**	**9**	**1**	**6**	**4**	**9**	**2**	**8**	**4**	**3**	**1**	**139**

Table E.2a-1: Data used for Chi-Square test, the relationship between elevation and Dvāravatī sites in river basin level

Elevation (m)	**Bang Prakong**	**Chao Phraya**	**Mae Klong**	**Tha Chin**	**Others**	**Grand Total**
0-50	17	28	13	18	22	98
>51	1	6	2	1	31	41
Grand Total	**18**	**34**	**15**	**19**	**53**	**139**

Table E.2b-2: Additional detail of Table E.2b-1

G	Elevation (m)	BP	CP	MK	TC	Other River Basins												∑
						C	M (NE)	M	N	PS	PN	PR	P	PC	SK	TS	Y	
0-50	0-50	17	27	13	18				1	1	4	9		4	3			97
>50	51-100	1	7	1	1					3			1	3	1	3	1	22
	101-150					3		4		1				1				9
	151-200			1		2	1	4		1								9
	201-250							1										1
	251-300												1					1
	Total	**18**	**34**	**15**	**19**	**5**	**1**	**9**	**1**	**6**	**4**	**9**	**2**	**8**	**4**	**3**	**1**	**139**

VITA

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